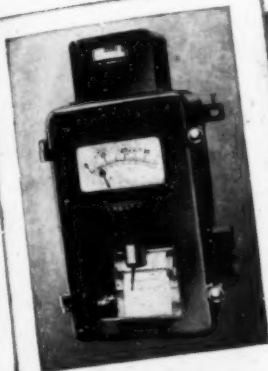
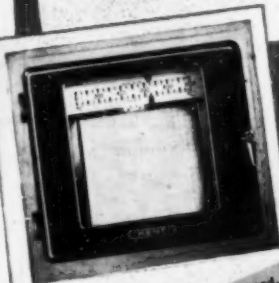


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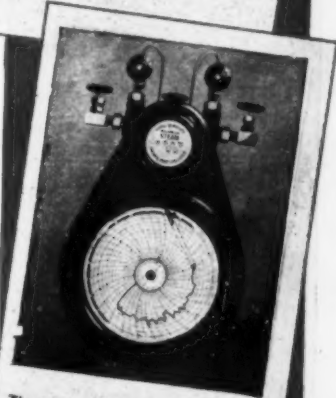
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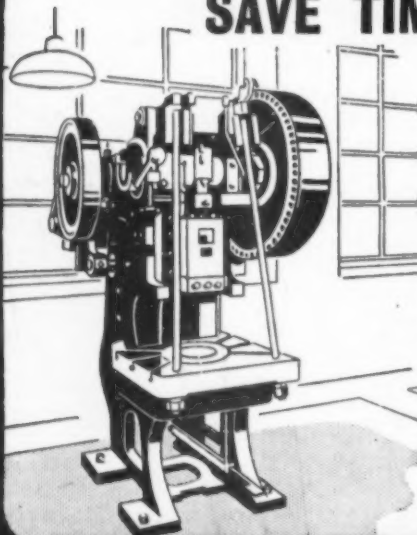
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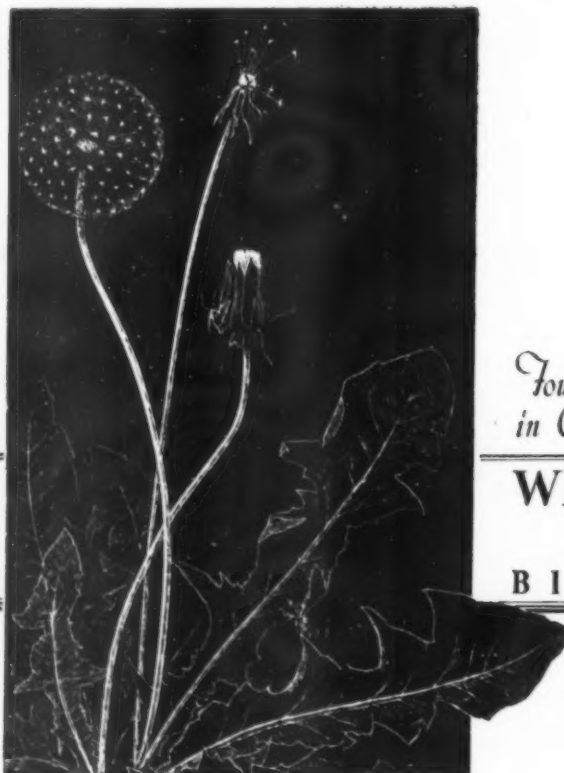
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## Economy in the Use of Ferro-Alloys

By Dr. W. H. Hatfield, F.R.S.

*In times of peace international trade throws open to all countries the world's resources in raw materials and facilities on an economic basis; war rudely disturbs this state of things and realism in production must then deal with a limited or changed availability of that upon which production can continue. These conditions apply at the moment to the production of steel, for which the demand for alloying elements is far in excess of their availability, and the steel industry is faced with the problem of catering for a greatly increased demand for steels possessing the necessary properties with a changing availability and a considerable deficiency in some of the essential elements. Efforts to meet this situation within the industry are being advanced by the friendly and enthusiastic collaboration of many minds, and a workable scheme is being operated. The author discussed this subject at a Conference on Mineral Resources and the Atlantic Charter, held recently by the Social and International Relations of Science Division of the British Association; his views can be regarded as complementary to his recent discussion on Special and Alloy Steels,\* as will be noted in this article we are permitted to publish.*

IN times of peace, particularly if they are of long duration, the qualities and characteristics of that which is produced are the result of tradition and usage, salesmanship and the developments due to technical progress based on the application of old or new knowledge. Tradition, usage and salesmanship slow up in measure the inevitable progress towards the realistic efficiency possible through knowledge and the consolidation of technical progress. War and preparation for war insists upon stark efficient realism, and those who prepare for war are given more time to attain to it than those who are unexpectedly called upon to face such conditions. Also in times of peace international trade throws open to all countries the world's resources in raw materials and facilities on an economic basis; war rudely disturbs this state of things and realism in production must then deal with a limited or changed availability of that upon which production can continue.

These conditions apply at the moment to the production of steel, and particularly to special and alloy steels. Concerted efforts are being made within the industry to attain maximum efficiency based on the availability and changing availability of raw materials and facilities. It will be obvious that technology and technique so developed can be, and will be, projected with advantage into post-war times.

It is perhaps of value to consider the 25 elements which are of direct interest in the production of steel. In the attached table those elements will be found scheduled. They can be divided substantially into four groups—i.e., (i) the dominant alloying elements, (ii) the secondary alloying elements, (iii) appertaining and arising essentially as regards process, (iv) for protective coating.

Of these 25 elements, knowledge of seven, copper, zinc, carbon, tin, lead, sulphur, and last but not most important of all, iron, was bequeathed to us by early civilisations, and a period of some two thousand years passed before we seriously began isolating those which are now so useful.

Of the dominant alloying elements, i.e., manganese, chromium, nickel, molybdenum, tungsten, cobalt and vanadium, it is of great interest to note that four of these elements were originally isolated in Scandinavia, one in France, one in Germany, and one in Spain, whilst of the secondary alloying elements, aluminium, titanium, zir-

TABLE OF THE ELEMENTS OF INTEREST IN STEEL METALLURGY.

Element.	Group.	Date Isolated.	Metal Isolated by	—
Hydrogen .....	I	1766	Cavendish	British
Copper .....	I	Prehistoric	—	—
Zinc .....	II	Prehistoric	—	—
Aluminium .....	III	1854	H. St. C. Deville	French
Carbon .....	IV	Prehistoric	—	—
Silicon .....	IV	1854	H. St. C. Deville	French
Titanium .....	IV	1825	Berzelius	Swedish
Zirconium .....	IV	1824	Berzelius	Swedish
Tin .....	IV	Prehistoric	—	—
Lead .....	IV	Prehistoric	—	—
Nitrogen .....	V	1772	D. Rutherford	British
Phosphorus .....	V	1669	H. Brand	German
Vanadium .....	V	1830	Sefstrom	Swedish
Arsenic .....	V	1240	Albertus Magnus, Bishop of Regensburg	German
Niobium .....	V	1801	Hatchett	British
Oxygen .....	VI	1774	Priestly	British
Sulphur .....	VI	Prehistoric	—	—
Chromium .....	VI	1798	Vauquelin	French
Selenium .....	VI	1818	Berzelius	Swedish
Molybdenum .....	VI	1782	P. J. Hjelms	Swedish
Tungsten .....	VI	1783	F. D. and H. J. D'Elhuyser	Spanish
Manganese .....	VII	1774	J. G. Gahn	German
Iron .....	VIII	Prehistoric	—	—
Cobalt .....	VIII	1742	Georg Brandt	Swedish
Nickel .....	VIII	1791	Cronstedt	Swedish

conium, niobium, selenium and copper, three were isolated in Scandinavia, one in France, and one in Britain, whilst the last mentioned, copper, was employed in prehistoric times.

As regards the elements iron, carbon and silicon, these are so fundamental as almost to escape notice; but whilst iron and carbon date from prehistoric times, silicon was only isolated in 1854 in France. Hydrogen, nitrogen, phosphorus, arsenic, oxygen, sulphur are to be looked upon as essentially impurities arising from process, whilst zinc and tin are used for coating steel in protection against rust (as, of course, in smaller degree are cadmium and nickel).

In an effort to be able to present a complete picture the author sought to—

- Schedule the production of the relevant raw materials as regards country of origin.
- Schedule the countries where the raw materials were smelted or reduced to a usable form.
- Schedule the origin of the relevant raw materials used by the different steel-making countries.

Such statistical evidence merits careful study, and, although not sufficiently available for a complete statement, does point to facts of great interest to this meeting.

### Raw Materials

The volume of production of an ore in a country is indicative of the achievement of economical winning, but not necessarily of the resources prevailing. There may be great quantities of low-grade ore, railways may not be available, and population of a suitable character may not be there. Distance, too, is determining from the economic point of view; for instance, a great country may find it advantageous to obtain material from a neighbouring country rather than from within the confines of its own extended territory. The geologist locates, the mining engineer advises on practicability, and the industrialist, backed by adequate finance, seeks to develop these relevant deposits. Sound knowledge, enterprise and no little courage is demanded. The collective outcome, normally, is availability in reasonable relationship to world demand.

Without exception the steel-making countries do not possess complete essential resources, and must import much that is necessary. In normal times international trade provides the necessary facilities at world prices on a reasonably economic basis. Small countries as well as large ones have successfully developed important steel industries.

To implement the foregoing, it is interesting to examine a few cases and then it will be obvious, having in mind present world conditions, that it is essential to use available alloys on their intrinsic technical merits, and only to the absolutely essential degree.

As regards the principal alloying elements used in the alloy steel industry, manganese ore, whilst widely distributed is produced essentially in Russia, India, West and South Africa, Brazil and Germany. Nickel-ore production is focused essentially on localised deposits in Canada. Chrome ore, whilst very widely distributed is produced in Rhodesia and South Africa, Turkey and U.S.S.R., and in lesser degree in Cuba, the Philippines, India, Yugoslavia and Greece. Tungsten ore is essentially produced in China, Burma, and, in less degree, in the U.S.A. and South America. Molybdenum ore production is focused essentially on deposits in the United States of America. Vanadium ore is produced essentially in Rhodesia and South-West Africa, U.S.A. and Peru. Cobalt ore is derived principally from the Belgian Congo, Rhodesia and Canada.

It will thus be seen that the principal steel-producing countries, U.S.A., U.S.S.R., Germany, Great Britain, France, Japan, Belgium, Luxembourg and Scandinavia are dependent upon the normal functioning of international trade and copious transport, particularly in the form of shipping.

Great Britain relies upon importing 30% of her iron ore and the whole of her manganese, chrome, nickel, tungsten, molybdenum, vanadium and cobalt. Germany relies upon importing most of her manganese ore and the whole of her chrome, nickel, tungsten and molybdenum; she claims to recover her vanadium at home. The U.S.A. imports over 90 per cent. of her manganese ore, and practically the whole of chromium, nickel, cobalt and a substantial proportion of her requirements in tungsten. It is thus obvious that the conditions postulated in the fourth clause of the Atlantic Charter did operate even in the period between the two great wars, or how can one explain, for instance, the successful iron and steel industries of Scandinavia and Belgium-Luxembourg.

### Properties Conferred by Certain Elements

One of the greatest technical achievements is the colossal output of iron, and, by virtue of the influence which carbon and other elements can confer readily upon it, a very wide range of properties is available. Steel may be soft and ductile, hard and of great strength, wear-resisting, rust- and acid-resisting, heat-resisting; may be of high permeability,

capable of a high degree of permanent magnetism, may be non-magnetic, have a high electrical resistance, or a low coefficient of expansion. It may possess various combinations of these and other properties as required. It can be converted by added elements into any of a wide range of tool steels, and steels for many special applications. These results are attained by a knowledgeable heat-treatment superimposed upon a selected suitable composition.

Some fifteen elements are involved in the production of these various properties, and it will at once be apparent that millions of alloys of various compositions would need to be tested out really to put this phase of metallurgy upon a finally quantitative basis. Thus, some properties may be achieved by using different proportions of different elements, and that fact, coupled with other factors operating in the world, has resulted in quite a complexity as regards the number of steels available. The obvious thing is for the producer and user in co-operation to use only those compositions which are most effective and most in sympathy with the availability of the materials.

The problems before such a collaboration are influenced by many variables. There is the peculiar combination of properties required for a particular purpose, achieved by complex compositions which, although they in practice achieve their purpose, have been found to do so by practical trial; that is, by "trial-and-error" method; and it is not always easy in a steel containing a number of alloyed elements in different proportions to diagnose the extent to which amounts of each individual element contributes, or to what extent the selected superimposed heat-treatment is responsible for the ultimate result. Again, it can be argued that so long as the necessary mechanical and physical properties are secured, the composition and treatment are of secondary importance; this might truly be argued, were it possible by testing methods alone to ascertain completely whether the conditions for a particular service have been achieved. Laboratory tests to simulate the calls of service are valuable, but they are generally incomplete. Even the designer, try as he may, is never sure of being able to postulate completely on paper the conditions which he has to meet and then provide the means of meeting them.

Thus, by practical experimental procedure, based on existing knowledge, mechanisms and apparatus are provided built of materials which, by trial, are found to serve the purpose. It is, therefore, not a matter of surprise that when success has been painfully achieved by modifications here and there, as dictated by circumstance, the means whereby success has been achieved are fairly rigidly adhered to. When stock is taken in a national emergency, multiplicity of types of material and of design is to be expected. The next step is to facilitate mass production by strictly limiting the number of designs and vastly reducing the number of types of material.

### The T.A.C. Schedule

What has been done as regards the metallurgy of steel, particularly as regards special and alloy steels? In May, 1940, the Special and Alloy Steels Committee constituted its Technical Advisory Committee with a mandate to deal with this problem. It was found that the production of the steels was governed by between two and three thousand specifications. The first step was, therefore, a meticulous study, which resulted in the sorting out of the whole of the steels covered by the specifications, into 85 categories essentially upon the basis of mechanical properties, compositions or special functions. The T.A.C. Schedule, 1 to 85, did not lend itself to general publication since it was all embracive, but it permitted the appropriate authorities and individuals to survey the interesting position thus disclosed.

The main point achieved was that it became possible to measure up needs against availability as regards the essential alloying elements. Means were found by the Steel Control,

assisted by the good will of the industry, and the consumers, to accommodate manufacture with quite reasonable success to changing conditions. Still conditions change, but in the truly indigenous British manner of adaptation to changing circumstance, the means of adaptation now exists which, it may be presumed, will achieve as much as is possible according to the existing conditions and needs of the moment.

The T.A.C. Schedule of 85 categories for so many specifications was possible owing largely to the manner in which the same object was being achieved by different or slightly different compositions and treatments. Thus, as will be described, selection was possible of a relatively few appropriate compositions and treatments to facilitate mass production, but at the same time alternative steels became scheduled, and so material guidance exists for change with availability as the need arises. How far can results be achieved without alloy conditions? How far can we replace nickel with chromium, or chromium with nickel? How, and in what circumstances are molybdenum and vanadium essential? Can we replace tungsten with molybdenum, or molybdenum with tungsten? Will a modified heat-treatment with a different composition give the same characteristics? A survey of the categories of the schedule assists in answering some of these questions.

In 1941 advantage was taken of the existence of the British Standards Institution to issue document B.S.970/1941, giving in the form of 58 specifications the principal and most useful of the steels in the schedule covering Wrought Special and Alloy Steels for General Engineering purposes in dimensions up to 6-in. ruling section. This document was shortly followed by B.S.971, which implemented the contents of B.S.970/1941 with much technical and other useful data facilitating the successful application of the selected steels; this document sets a precedent in form. At this stage the Steel Controller issued a Direction through the British Standards Institution, B.S.970A, indicating that in conformity with existing conditions certain steels specified in B.S.970/1941 should, in the absence of special sanctions be the steels applied in future programmes. Thus, the "En Series" of war steels entered their useful career. On March 30, 1942, a brochure was issued indexing and correlating the great mass of specifications to the steels of the Direction 970A, which sought to replace them. Two remaining steps should be mentioned: B.S.970/1941 was revised, and is reissued as B.S.970/1942, and representatives of all the Services, after deliberation upon the steps already taken, issued through the British Standards Institution document B.S./S.T.A.5, which co-ordinates the whole of the requirements of the Services within the terms of reference with the composition and properties of the steels of the Direction on the basis of the En series contained in B.S.970/1942.

This successful collective effort at unification has only been possible as a result of the firm determination of all parties to attain that which was intended. Finality under present changing circumstances is not possible, but succeeding documents under the aegis of the same authorities will it is hoped, successfully keep up to date such essential data.

### Carbon Steels

The fortunate Crusader had a superbly efficient Toledo sword of high temper—that is, the blade had a tensile strength of over 100 tons per sq. in. This was obtained by the diffusion of carbon into wrought iron, and the steel so produced when heated above the critical point became a solid solution of carbide, or carbon in iron; rapidly quenched in water from this temperature the blade was intensely hard and also brittle, but when lightly tempered by reheating to a skilfully selected temperature, material hardness was still retained but was accompanied by a remarkable toughness. Such results can only be obtained in such thin sections; if heavy pieces of such steel are quenched from the hardening temperature, the actual rate

of cooling becomes so relatively slow as to allow the solid solution to break down and hardening is not achieved. Nevertheless, modern carbon steels which, different from the steel of medieval times, contain a substantial quantity of manganese, may be hardened and tempered in the form of bars of quite useful sizes, with resultant considerable strength and ductility. The exploitation of such material to the greatest practical extent is most desirable at the present time.

The use of a particular composition of steel necessary for a particular application is governed by the strength and properties required, and by the sectional area or, to be more correct, the "Ruling Section." If the mass is considerable, and the strength required great, a rich alloy steel is essential to ensure success in hardening, and therefore the possibility of superimposing upon the quenched condition by tempering a desirable toughness associated with the degree of strength required. This short paper does not permit a detailed discussion of this particular field, but the relevant information will be found in the documents to which reference has been made.

### Heavy Masses

In heavy masses, where it is desired to obtain properties resulting from hardening and tempering, as much as 5-6% of alloying elements is necessary—i.e., chromium and nickel, and these elements may be used in different proportions with a material degree of interchangeability, according to availability. Under such conditions a small proportion of molybdenum is desirable essentially to preserve higher values in resistance when required to the notched-bar impact test, and in part to reinforce the hardening properties. As the mass or section decreases, less alloy is needed, and this aspect is given quantitative guidance on alternate bases in B.S.970/1942 and B.S.971. Thus, the heavy use of alloying elements should be restricted according to mass.

The remarks so far refer to the development of strength and hardness in different degree by the processes of hardening and tempering. There are a considerable number of instances where alloys used in greater quantities produce important and entirely different characteristics. 13-30% of chromium and 2-20% of nickel together with lesser amounts of other elements are necessary to produce rust-, acid- or heat-resisting steels. Large quantities of tungsten and/or molybdenum together with material quantities of chromium, vanadium and cobalt are used to produce high-speed cutting steels. High percentages of manganese are necessary to produce the wear-resisting properties of the austenitic manganese steel. Many other special purpose applications could be quoted. The use of such steels, owing to their high alloy content, is being carefully watched and controlled.

The problem is a considerable one—namely, how at the present time to cater for a greatly increasing demand for steels of the necessary properties with a changing availability and a considerable deficiency in some of the essential elements. Never has a more interesting technical situation developed, for solution by scientific and technical minds.

Autocracy in science or technology is as deadly as in the political field. In these efforts within the steel industry our work is being advanced by the friendly and enthusiastic collaboration of many minds; the co-ordination of different points of view has resulted in, and is operating, a workable procedure.

Stark efficient realism is necessarily our theme.

The Canadian War Advisory Committee is rapidly preparing an inventory of Canada's mineral resources in co-operation with the Metals Controller, Mr. George Bateman. New deposits are being carefully investigated, an official statement says, and special attention is being given to the possibility of opening deposits previously considered unprofitable.

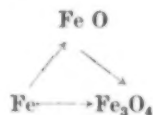


## The Crystal Structures of Fe, FeO and Fe<sub>3</sub>O<sub>4</sub> and their Interrelations

IT has been established by X-ray tests that the oxidation of pure iron and ferritic steels at elevated temperatures under conditions implying a restricted supply of oxygen or short-time heating produces the two phases FeO (wüstite) and Fe<sub>3</sub>O<sub>4</sub> (magnetite).  $\alpha$ -iron from the parent metal is liable to be present as a third phase. On the other hand, hæmatite, Fe<sub>2</sub>O<sub>3</sub>, has never been observed under these conditions. There seems to be a barrier to its formation, though it is a common product of oxidation when the contact with oxygen is continuous and unrestricted, and time is allowed for the reaction to approach equilibrium.

As an example of the former conditions may be quoted the process of dry-wear of iron and steels which have been studied by X-rays<sup>1</sup>, and yielded the result that the abraded powdery products of wear consisted of  $\alpha$ -iron, FeO and Fe<sub>3</sub>O<sub>4</sub>, in various proportions, but not Fe<sub>2</sub>O<sub>3</sub>. Under the heading "limited accessibility of oxygen" can also be considered the products of corrosion of steel in close contact with the metal, which are to some degree "protected" by the outer layers of scale. On iron exposed to the atmosphere at 1,000° C. the innermost layer of scale was found to be pure wüstite.

This subject has been studied by H. J. Goldschmidt, and is discussed in his recent paper published by the Iron and Steel Institute, in which he shows that the structures of the phases  $\alpha$ -iron, FeO and Fe<sub>3</sub>O<sub>4</sub>, have not merely the common feature of cubic symmetry, but that simple quantitative relations exist which facilitate a ready transition between the phases by relatively small atomic readjustments. Fe<sub>2</sub>O<sub>3</sub>, on the other hand, has a fundamentally different crystal structure (rhombohedral, corundum type), and the energy barrier to its formation from the cubic phases will be greater than is the case during the transformations:—



For reference, the iron-oxygen equilibrium diagram is shown in Fig. 1, as given by Hansen.<sup>2</sup> While considerable uncertainty still attaches to the part Fe<sub>3</sub>O<sub>4</sub> to Fe<sub>2</sub>O<sub>3</sub>, the liquidus curves and the accurate phase boundaries of wüstite, the general characteristics of the phase fields in the part Fe-FeO-Fe<sub>3</sub>O<sub>4</sub> may be regarded as established, in particular the eutectoid transformation 4 FeO  $\longrightarrow$  Fe and Fe<sub>3</sub>O<sub>4</sub> at 570° C. A diagram showing phase boundaries determined by many workers, as well as numerous references, may be found in the paper by Pfeil and Winterbottom.<sup>3</sup>

In the present paper the author includes results of some X-ray tests on layers of scales formed on pure iron, mainly to illustrate two points:—

1. The decrease of the wüstite lattice constants with decreasing iron content.
2. The effect on the structure of the scale of exposing either  $\alpha$ -Fe or  $\gamma$ -Fe to oxidising conditions.

The latter preliminary experiments revealed the innermost layer of scale to be pure wüstite if formed at, and quenched from, temperatures above A<sub>3</sub>, and wüstite plus magnetite below A<sub>3</sub>, the proportion of magnetite increasing with decreasing temperature.

The facts discussed in this paper have a bearing on the problem of the corrosion resistance of steel.

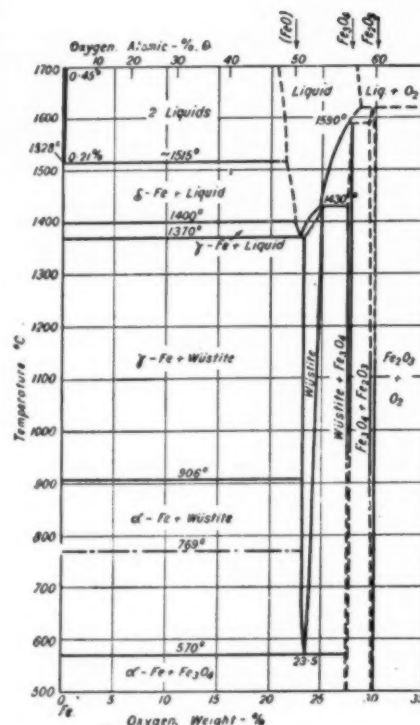


Fig. 1.—  
Iron-oxygen  
system, ac-  
cording to  
Hansen.

## Forthcoming Meetings Institute of Metals

THE Thirty-fourth Annual Autumn Meeting will be held on Wednesday, September 23, at 4, Grosvenor Gardens, London, S.W. 1, beginning at 3 p.m. After the conclusion of the formal business, the following papers will be presented for discussion:—"The Cold-Pressing Properties of Duralumin-Type Alloy Sheets, with Special Reference to Large Pressings for Aircraft," by J. C. Arrowsmith, K. J. B. Wolfe and G. Murray; and "Railway Bearing Metals: Their Control and Recovery," by J. N. Bradley and Hugh O'Neill.

## Iron and Steel Institute

A JOINT Meeting of the Manchester Metallurgical Society, and the above Institute has been arranged to be held on Wednesday, September 30, at 6-30 p.m., at the Engineers' Club, Albert Square, Manchester. Mr. J. Sinclair Kerr (Member of Council of the Iron and Steel Institute) will preside, and Prof. J. H. Andrew will present the paper by himself and Dr. H. Lee entitled "The Work-hardening and Ageing of Steel."

## Sheffield Society of Engineers and Metallurgists

A MEETING of the above Society is arranged for Saturday, September 26, at the Royal Victoria Station Hotel. The meeting is timed to commence at 2-30 p.m., and Dr. W. H. Hatfield will be in the chair. The lecture will be by Dr. H. Sutton, of the Royal Aircraft Establishment, and his subject will be "Steels in German Aero-Engines and Aircraft."

## Sheffield Metallurgical Association

A MEETING of the above Society is arranged for Saturday, October 10, at 198, West Street, Sheffield. The meeting is timed to commence at 2-30 p.m., and Dr. E. Gregory, President of the Association, will be in the chair. The lecture will be by Dr. W. H. Hatfield, of Brown-Firth Research Laboratories, whose subject will be "The Rationalisation of Specifications to Meet Wartime Needs."

<sup>1</sup> Goldschmidt and Harris, *Journal of Scientific Instruments*, 1941, vol. 18, May, p. 94.

<sup>2</sup> Hansen, "Aufbau der Zweistofflegierungen," p. 706. Berlin, 1936: Julius Springer.

<sup>3</sup> "Review of Oxidation and Sealing of Heated Solid Metals," London, 1935: H.M. Stationery Office. Article by Pfeil and Winterbottom, p. 18. References to wüstite region.



# METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER"

## Wartime Activities of Technical Institutes

**M**ANY do not fully appreciate the valuable work being done by the various technical institutes as their contribution to the war effort. We have heard criticism on time wasted in some works in solving problems that have been previously solved in other works, and some have expressed the opinion that the need exists for centralised co-ordination of technical and scientific research and development, and for real pooling of information and facilities between Government departments, between manufacturers, and between Government departments and manufacturers. Actually this is being done and frequently the difficulty is due to the inability of individuals to take advantage of facilities that are available. The various institutes are doing their utmost to co-operate with members, and in this way are contributing enormously to the smooth working of industry, but in many respects they are initiating work of great importance to the nation at this time of emergency. It is not possible to detail this work here, but it is profitable to summarise the work being done by the Iron and Steel Institute and the Institute of Metals as typical of the activities of many institutes in wartime.

### The Iron and Steel Institute

**T**HERE was a fairly widespread feeling on the outbreak of war that research would not be needed, and that institutes designed to encourage it would not be able to play any useful part in the country's emergency.

A very short experience of operations under wartime conditions was sufficient to prove even to the most hardened sceptic how wrong this view was. Fortunately, for the iron and steel industry, and the country, the Research Committees of the Iron and Steel Industrial Research Council, for which the Iron and Steel Institute is responsible in conjunction with the British Iron and Steel Federation, did not share the prevailing pessimism. They are as active as, if not more active than, before the war, and the quality of their work is certainly as high; but there has been a change in emphasis. Long-range researches, however cherished, have in most cases been discontinued, and work on new problems of immediate importance has been given prominence. As a result there has been a tendency, which some will not regret, to produce clear-cut answers to particular questions rather than reports which themselves raise new problems.

The opinion of those, however, who have always held that there was no true distinction between fundamental and practical research has been justified. It is the long-range researches of the past that are proving most useful at the present time, and it has become clear that the solution of certain problems, which have an important bearing on production, will only be reached by a fuller understanding of fundamental questions.

Among published work, and reference can be made here only to published work, attention may be drawn particularly to

papers on the determination of oxygen and gases in steel, the measurement of the temperature of liquid steel during the actual operations of steelmaking, and the conditions governing the cooling of steel in the ladle. Other important papers resulting from work instituted by research committees also include reports on the formation of hair-line cracks and the influence of hydrogen; impurities, inclusions and the structure of ingots; the formulation of standard methods of analysis, the protection of structural steelwork against corrosion and important investigations, undertaken at the request of the appropriate Government departments, which are calculated to assist foundries in the difficulties met with when casting unfamiliar products in moulding sands, and with the use of bonding materials which are different from those available in peacetime. Papers of a strictly metallurgical character indicate that the primary claims of production have not entirely diverted the attention of scientists from the study of the structure of metals.

In a somewhat different category are several important papers on refractories. They represent the result of researches put in hand by individuals or companies on their own initiative, or by committees for which the Institute has no direct responsibility. The work is of the highest quality, and has been of particular value in enabling existing resources to be used to the best advantage.

Literary activities of the Institute have been maintained in all essential respects. Research work is indeed of little value unless it is made known to those who can benefit from it. Consequently, the editorial department has been heavily drawn on in publishing material in the *Journal*, or in preparing communications for limited circulation when the subject has been confidential. Abstracts of technical literature continue to be published monthly, and a wartime departure has been an extended service for providing translations of foreign articles.

The best evidence, however, of the need for technical information in an industry which is engaged full-time in the production of materials essential to the nation's wartime economy is the record number of loans made from the Joint Library of the Institute and the Institute of Metals; these numbered nearly 6,000 in 1941.

It is only in the sphere of meetings and in social contacts that the Institute's activities have been drastically curtailed. Difficulties of transport and rationing and the need for managers to spend as much time as possible in directing their plants have made it desirable to reduce meetings to the minimum required to communicate new information.

Social events, which in peacetime took a large place in Institute activities, have been discarded, including the annual dinner and the festivities which used to bulk so largely in the programmes of Autumn meetings. Some good work has, however, been found possible, even in this sphere. There was a pleasant renewal of pre-war contacts when the opportunity occurred of entertaining, and perhaps in a small way assisting, the distinguished members of the American Steel Mission which, as announced in the Press, has recently visited our country.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

## The Institute of Metals

THE existence of a state of war has had a stimulating effect on our scientific societies, as on most other organisations. It was the same in 1914-1918, when the Institute of Metals, then a newly formed body, doubled its membership because of the vitally important work that the Institute had to perform in relation to the dissemination of knowledge respecting the wartime uses of non-ferrous metals and their alloys.

Since the outbreak of the present war history has repeated itself at the Institute of Metals, now admirably housed (with the Iron and Steel Institute) in Grosvenor Gardens, whereas 1914 saw the Institute renting two small rooms in Caxton House. The largely increased accommodation, including a fine Joint Library, had been acquired very fortunately, in the summer of 1938, just in time for everything to be put into good working order by the time war broke out a year later.

The work accomplished during the past three years has been, of course, largely of such a nature that it cannot now be made public. Assistance and advice has been given freely to members engaged on war work, as well as to Government Departments. The extensive Joint Library, containing the finest collection of metallurgical literature in the country, has issued more books than at any time since its formation, whilst the Information Department has been correspondingly busy with "war" enquiries.

A feature of the work of the Institute of Metals that has been of great service to those engaged in the non-ferrous industries has been the continued issue of the invaluable abstracts that are published, month by month, in the *Journal of the Institute of Metals*. Particularly appreciated have been the abstracts of metallurgical papers appearing in enemy countries. Soon after war broke out it appeared that this source of information would no longer be available. However, it was found possible to have the abstracts from Axis publications prepared in the United States until that country came into the war, and now the work is proceeding with the assistance of other helpers.

The publication of papers containing the results of original research—the prime function of the Institute of Metals—has naturally been hindered by the requirements of the censorship. There exists, in fact, a number of "hush-hush" papers that cannot see the light until after the conclusion of hostilities. Exactly the same situation arose during the last war, and it resulted in such a flood of matter for publication that the *Journal* became of unwieldy size and provided the Council with grave financial problems. Profiting by this experience, the Council has already instituted a wartime emergency fund to which firms in the industry are generously making annual contributions of such a substantial nature that the Council should have available the necessary money to permit of the publication of these papers in due course without causing any financial embarrassment to the Institute.

However, it must not be supposed that it is a case of "jam yesterday and jam to-morrow, but never jam to-day." Actually, some extremely important and immediately useful papers are being published regularly in the Institute's *Monthly Journal*. Furthermore, a selection of these papers is offered for discussion by members and visitors at the Spring and Autumn meetings of the Institute. Although, owing to the Defence Regulations, these discussions have to be regarded as confidential, they have proved exceedingly useful, leading, in many cases, to practical developments in connection with the production of war material.

Similar discussions have taken place at meetings of the local sections of the Institute. These meetings, so useful have they proved, have become increasingly frequent as the war has progressed, and are now being held throughout the summer months, instead of, as usual, only during the winter, by some of the local sections.

Members of the Forces from overseas, including those

belonging to several of the United Nations, when in London have visited the Institute's headquarters to obtain technical information and advice. They have been particularly keen to establish contacts with members working on problems similar to those on which they were engaged in their home towns; this interchange of experience should prove exceptionally valuable. But for the war, and the Institute of Metals, these men would probably never have had an opportunity of getting together.

The need for the latest scientific information regarding the progress of non-ferrous metallurgy not only in Great Britain but throughout the world has resulted in a remarkably increased demand for copies of the *Journal of the Institute of Metals*, particularly from the two foreign countries where the production and use of light alloys for aircraft construction is at its zenith—the United States and Russia. So urgently are the *Journals* needed in the U.S.S.R. that it is no uncommon event for several cabled orders for *Journals* to be received at the Institute's office in a single week.

Abroad, the work of the Institute has been advanced during the war to a notable extent by the activities of the distinguished gentlemen who act as honorary corresponding members to the Council in all those countries where there is a large grouping of members. The contacts of these professors, engineers, metallurgists and industrialists with the Council have been most helpful.

Active work is proceeding at the Institute's headquarters on post-war problems. It is realised how necessary it will be, when peace comes, to stimulate the use of non-ferrous metals and their alloys in place of the substitutes that, in some cases, have had to be employed under war conditions. In the building industry, for example, there is vast scope for the greater use of non-ferrous metals, whilst aircraft and motor-car production after the war will absorb enormous quantities of these metals and their alloys.

## North-East Coast Institution of Engineers and Shipbuilders

COMPREHENSIVE arrangements have been made by the above Institution for the 1942-43 session. The annual general meeting will be held on October 16, when Mr. J. Ramsey Gebbie, B.Sc., will be installed as president by Mr. W. A. Woodeson, retiring president. The Andrew Laing Lecture will be given by Messrs. R. A. Adam, F. C. Holmes, B.Sc., and A. W. Perrins, M.Eng., on October 30, and the subject will be "Colloidal Fuel." Papers covering a wide range of interest will be read at various meetings throughout the session, and efforts will be made to bring these to the notice of readers when the dates of meetings have been fixed.

## Wrought Light Alloys Development Association

WE are advised that the address of the above Association is now Union Chambers, 63, Temple Row, Birmingham, 2. The registered office of the Association remains at 25, Bennett's Hill, Birmingham, 2, to which all communications for the Secretary should be forwarded. Note that the telegraphic address has also been changed to "Lightaldev, Birmingham."

The change of address has been made necessary by the increase in work of the Association, particularly the Advisory Service Bureau and Information Department. As readers will know, the resources of the Association are available, without charge or obligation, to all engaged on the treatment or manipulation of wrought aluminium alloys. All enquiries and requests for technical advice or assistance should be addressed to the Manager, Dr. E. G. West. Requests for publications or the loan of literature from the Association's library should be made to the Information Officer, Mr. T. D. Smith, B.Sc.

# Metallic Wear of Metals and Alloys

By J. W. Donaldson, D.Sc.

*There are so many processes by which the wear of metals may occur that every user of metals, in a varying degree, is faced with the problem of counteracting it. The mechanism of wear involves a large number of independent factors, and experimental and research work on these factors are discussed in an endeavour to discover the mechanism of wear, so that the results may be applied to the development and selection of new alloys or the treatment of existing alloys to improve resistance to wear under service conditions.*

**W**EAR which involves deterioration and failure of metals in service occurs in every branch of mechanical engineering as well as in other industries, and is a problem which every engineer or other user of metals has got to face to a greater or less extent. Many types of engineering and industrial machinery are subjected to frictional wear, so that a continual replacement of worn-out metallic parts is necessary, together with a large additional consumption of power required to overcome frictional resistance in the running of such machines. The annual cost of such replacements and of such power losses must amount to a very considerable sum, but like the cost resulting from corrosion, it is difficult to estimate. Metallic wear is most noticeable in such engineering and machinery parts as cylinder liners, valves and cams for internal combustion engines; in dies, shear blades and rolling mill machinery in steelworks; in machinery used for excavating in the mining industry; in machines used in the handling of powdered materials, in many parts used in road and rail transport, and in cutting tools.

The wear of metals which occurs in different industries and in different engine units and industrial parts, is not always produced by the same conditions, so that not only is it difficult to define wear, but it is also difficult to study the actual mechanism of wear. There are many processes by which the wear of metals may occur, and these include (1) wear due to sliding friction with lubrication of uniform bearing surfaces, (2) heavy wear which occurs with unlubricated surfaces or with water present, (3) wear due to high temperatures and oxidising conditions, (4) wear of cutting edges of tools, (5) wear due to flaking, and (6) fretting corrosion between round or flat surfaces in the dry state or with insufficient lubrication.

To counteract and overcome those different types of wear, many new steels and special wear-resisting alloys have been introduced, steels and cast irons have been subjected to special hardening processes, new bearing metals have been developed and new lubricants have been used. All these factors have helped to solve the problem of wear to a certain extent, but in spite of this progress little is known about the actual mechanism of wear, and it is only during comparatively recent years that fundamental scientific research on the wear of sliding and other surfaces has been carried out. From the results of such investigations certain theories have been evolved, and these are now beginning to be found useful in the development and selection of new metals and bearing alloys for service conditions.

In investigating the mechanism of wear a large number of interdependent factors are involved which render it difficult to correlate isolated tests, even approximately, with service conditions. Many different types of tests have been designed and used for determining the wear resistance of metals and alloys, but the results obtained from these tests in general show only the resistance of the material under test to the limited wearing conditions imposed by the testing machine. It would appear that wear, like corrosion, depends on conditions of service and is not an inherent property of the material apart from its environment.

In reviewing the subject of metallic wear, it is therefore necessary to define wear, to consider the various empirical tests designed to ascertain the relative rates of wear of

different metals under similar conditions and the same metal under different conditions; to discuss the experimental and research work carried out on the various factors involved in the process of wear and from such work to discover the mechanism of wear, and to apply the results obtained to the development and selection of new alloys or the treatment of existing alloys, in order that the best results may be obtained under service conditions, so that wear is reduced to a minimum.

## Definition of Wear

Metallic wear is usually defined as the undesired gradual change in dimensions which occurs in service under frictional pressure as the result of dry or imperfectly lubricated metals being in contact with each other or with non-metallic substances. Defining wear in such a manner distinguishes it from grinding, lapping, polishing, "wearing in," or other processes which produce an intentional removal of the metallic surface. Wear may occur under different conditions, either by abrasion, by corrosion and erosion, or by galling, seizing, or scoring, but whichever type occurs it usually takes place in two stages. In the first stage, during the "running-in" period, a chemical, physical or mechanical modification of the surface takes place, resulting in a polished or work-hardened layer being formed, and this layer is removed during the second stage, when the material from the altered surface is gradually removed by frictional forces.

In abrasive wear, which usually takes place when the wearing metal is in contact with some other metals or solid particles of grit, dust, or some other substance, mechanical distortion of the surface layers result in structural changes occurring, and is followed by removal of these layers by frictional forces, whereas with corrosion and erosive wear, which may occur between a liquid, gas, or vapour, there is usually an alteration of the surface layers by chemical attack or attrition, and such action is followed by removal of the altered layers by frictional forces. Wearing by galling, seizing or scoring, which is caused by loose metal particles or metal projections on one surface sliding against another, involve molecular adhesion or cohesion of the two bearing surfaces of the metals followed by a tearing out of small pieces from one surface or the other. Metallic wear may not only result from either of these three types of attack singly, but may also be a combination of two or all three types together.

## Wear Resistance Tests

In selecting metals for engineering and other parts, it is necessary to have data with regard to their wearing properties available, if the best results are to be obtained from their use. Tests which give information on the relative wearing properties of metals against a standard metal, of the actual rate of wear between different metal surfaces, of how wear is increased with sliding speed and with load, and on the influence of different types of lubricants, are therefore of value. To determine such information, many different types of wear-testing apparatus have been developed to yield data on the relative wearing properties of metal under conditions approaching those met with in service.



As wear is a relatively slow process, the principle used in the designing of most testing machines is to accelerate its rate and this is usually done by introducing some additional factor or by greatly altering the relative magnitude of the conditions imposed. As the process of wear also varies greatly with the material being tested and on external conditions, it is necessary to design laboratory testing apparatus, so that test conditions are as similar to those prevailing in service as possible. In this respect it is usually found impossible to use only one method of testing to determine the wear resistance of a given material in terms applicable to all circumstances, but it is possible, however, to determine the wear resistance of various metals and alloys under specified conditions and from the results obtained to determine whether such materials are suitable for the purpose for which they are intended.

Methods used for relative wear-testing include lubricated tests and unlubricated tests, the latter type being more generally used, as lubricated tests, although approaching more nearly to service conditions, take a longer time to carry out, due to measurable wear taking place slowly. Unlubricated tests include abrasion tests, blunt drill tests, rolling and sliding friction tests, reciprocating friction tests, rotating ring tests, and spindle tests. The best known standard tests are carried out on the Amsler wear-testing machine, the Skoda-Sawin wearing testing machine, and the Spindel wear-testing machine, but in addition to those testing machines, numerous tests have been carried out on apparatus specially designed to test wear under particular conditions.

In the Amsler testing machine, used for testing wear by rolling or sliding friction, two small discs, 1.5 in. to 2 in. diameter, run in contact with each other and in opposite directions. The pressure is kept uniform, but one roller may be run faster than the other to give 1% slip, so as to give partial sliding friction. The wear on both rollers is measured, and abrasives or lubricants may or may not be applied. The working tool of the Skoda-Sawin wear-testing machine<sup>1</sup> is a smooth rotating disc of tungsten carbide (Widia XX), 30 mm. in diameter, 2½ mm. wide, which under a constant load grinds an impression in a fixed test-piece, using a standard coolant. The volume of the impression ground on the test-piece is calculated from measurements made by a depth gauge on the machine, and this is a measurement of the wear-resisting properties of the material tested. In the Spindel testing machine, a flat test specimen is pressed against the edge of a rotating disc 1 mm. thick, rotating at a peripheral speed of 25 mm. per min. under a pressure of 5 kilograms. for soft materials and 10 kilograms. for hard materials. The disc acts as a blunt circular saw, and the surface of the segment ground away is used as a measure of wear. In some cases the amount of wear in the steel disc is also measured.

TABLE I.  
COMPARISON OF VICKERS HARDNESS NUMBERS WITH SAWIN WEAR NUMBERS.

Material Tested.	Vickers Hardness.	Sawin Wear No.
Tungsten Carbide (Widia XX) ...	1,050 ..	2.5
Stellite .....	780 ..	70
High-speed Tool Steel .....	920 ..	80
Tool Steel .....	830 ..	130
Chrome-Nickel Steel .....	360 ..	180
Chrome-Nickel Cast Iron .....	380 ..	190
High Duty Cast Iron .....	250 ..	210
Aluminum-Nickel Bronze .....	120 ..	220

The Skoda-Sawin testing machine measures the relative wear resistance of metals against a standard material. Results obtained with such a machine, showing the relative wear values obtained for different alloys, together with their Vickers hardness, are given in Table I. The results obtained show a slight relationship between wear and hardness. Results obtained with the Skoda-Sawin-machine, however, give no indication as to how different metals will wear when in actual contact with each other. Such data is best obtained with the Amsler testing machine, which measures rolling and sliding wear between different

metal surfaces in contact with each other by using different metals or alloys for the two revolving discs. With the Spindel testing machine the relative wear of different metals can be determined or the wear of various metals in contact with the steel forming the revolving disc compared. In Table II are given results showing the wear resistance obtained by Meyer<sup>2</sup> on various steels with the Amsler and Spindel wear-testing machine, together with their Brinell hardness. These results show that the Brinell hardness of a steel often bears no relationship to its rate of wear.

TABLE II.  
COMPARISON OF BRINELL HARDNESS NUMBERS WITH AMSLER AND SPINDEL WEAR VALUES (MEYER).

Material.	Brinell Hardness.	Amsler Machine 1% Slip 50 Kilogs. Wear in Grms.	Spindel Machine. Wear in Mg.
Mild Steel .....	120 ..	1.7 ..	150
Ordinary Rail Steel .....	220 ..	0.9 ..	130
Good Rail Steel .....	250 ..	1.7 ..	55
Air-hardened Alloy Steel .....	360 ..	1.1 ..	20

Although relative wear tests carried out in the laboratory with standard and other types of testing machines are of use for selecting materials for wear-resisting purposes, it is sometimes necessary to obtain such data by means of small-scale service tests. Engines and machinery running in the laboratory under controlled conditions and closely simulating those found in service, give very useful results, and are more easily supervised than tests under actual service conditions, which are often influenced by factors extraneous to the material being tested, such as design, lubrication, operation difficulties, etc.

Mochel,<sup>3</sup> in discussing wear from the power equipment viewpoint, states that although laboratory tests are essential in making a selection among possible wear-resisting materials for a given purpose, it is almost necessary, if reliable data is to be obtained, to run a particular section of the actual machine under service conditions, and states that such test equipment has been used for the selection of Stellite—55% cobalt, 30% chromium, and 5% tungsten—as a shield for turbine blades. Low carbon steel containing 13% chromium, 0.5% molybdenum has also been tested in a similar manner and found satisfactory for sealing strips used in turbines, and Stellite, chromium steels, age-hardened K Monel Metal, and nitrided steels have been selected by simulated service tests for such parts as valve seats, valve stems, and bushings for high-temperature steam.

TABLE III.  
SERVICE WEAR TESTS ON VALVE INSERT MATERIALS AGAINST AUSTENITIC EXHAUST VALVES (WILLIAMS).

Material.	Brinell Hardness.	Wear, In. per 50 Hours.
High-speed Steel .....	590 ..	0.001
Nickel Manganese Chromium Steel .....	195 ..	0.014
Steel Medium C. ....	139 ..	0.0415
Chrome-Molybdenum Cast Iron .....	402 ..	0.035
High Chromium Cast Iron .....	418 ..	0.0075
Austenitic Cast Iron .....	196 ..	0.026
Heat-treated Cast Iron .....	420 ..	0.014
Chromium Aluminum Cast Iron .....	248 ..	0.046
Nickel Cast Iron .....	174 ..	0.055
Stellite .....	641 ..	0.003
Chromium Plate .....	— ..	0.006
Monel Metal .....	149 ..	0.002
K. Monel Metal .....	265 ..	0.002
Copper Nickel Alloy .....	178 ..	0.0355
Copper Zinc Alloy .....	212 ..	0.034
Copper Zinc Tin Alloy .....	157 ..	0.034
Cast Aluminum Bronze .....	150 ..	0.04
Forged Aluminum Bronze .....	228 ..	0.025
Beryllium Alloy .....	332 ..	0.005
Nickel Beryllium Alloy .....	321 ..	0.004
Aluminum Alloy .....	92 ..	0.082

Tests of a similar nature are those carried out by Williams<sup>4</sup> to determine the most suitable material for use in internal combustion engine exhaust valves. In these tests, valve insert materials were tested against austenitic exhaust valves, being subjected to intense impact loading for 50 hours at speeds up to 2,750 r.p.m., at temperatures up to 700° C. in an oxidising atmosphere. The results obtained from these tests are given in Table III, and show that stainless steel, Monel Metal and other corrosion-resisting

<sup>2</sup> H. von Meyer. *Archiv. Eisenhüttenwesen*, 1936, vol. 9, pp. 501-508.

<sup>3</sup> N. L. Mochel. Symposium on Wear of Metals, Amer. Soc. of Testing Materials, 1937.

<sup>4</sup> C. G. Williams. *Engineering*, 1937, vol. 143, pp. 357-358, 475-476.

<sup>1</sup> *The Engineer*, 1939, vol. 167, pp. 184-185.



materials give the best resistance to oxidation wear, and that this resistance is irrespective of the hardness of the alloy.

In general, wear resistance tests and simulated service tests show that metallic wear is proportional to bearing pressures and sliding speed, that wear resistance is a function of the coefficient of friction, that the hardness of a metal or alloy often bears no relationship to its wear, and that the type of lubricant used and method of lubrication greatly affects wear.

### Wear Mechanism Investigations

The various factors which are involved in the process of metallic wear and the various ways in which such factors combine in contributing to an understanding on the mechanism of wear, include the consideration of such subjects as lubrication, and surface temperatures, running in and polished surfaces, cylinder wear, oxidation wear, and the seizure of surfaces.

**Lubrication and Surface Temperature.**—Some of the most important problems of wear are concerned with the lubrication of surfaces. The object of lubrication is to form a fluid film between the sliding surfaces and by replacing metallic friction by fluid friction to eliminate wear. If the fluid film has no chemical action on the metallic surfaces, if there is freedom from suspended solid matter in the film, and if the film is viscous, ideal conditions are approached, friction between the surfaces is reduced to a very small amount, and wear is reduced to a minimum. Such ideal conditions only take place, however, in certain very limited applications, and are seldom found in practice, particularly in the stopping or starting of a moving part. When conditions are such that the oil film is reduced in thickness and only an adsorbed layer of a few molecules thick remains, portions of the lubricated surfaces touch each other and give rise to the condition known as boundary lubrication. In boundary lubrication the nature of the lubricant and the characteristics of the sliding metals both affect the friction. Finally, when conditions are such that no film exists between the surfaces and where sliding surfaces are chemically clean and dry, friction is dependent on the nature of the surfaces and may attain a very high value. Investigations have shown that the coefficient of friction ( $\mu$ ) may vary from 0.002 for well-lubricated surfaces to 0.85 for dry unlubricated surfaces. Under conditions of boundary lubrication values varying from 0.08 to 0.2 are obtained, varying with the nature of the lubricant and temperature conditions.

TABLE IV.  
COEFFICIENT OF FRICTION OF VARIOUS OILS UNDER BOUNDARY LUBRICATION (DONALDSON AND HUTCHISON).

Temperature.	Fixed Oil.	Mineral Oil.	Compounded Oil.	Mineral Oil + Oleic Acid.
60° F. ..	0.088 ..	0.136 ..	0.100 ..	0.112 ..
200° F. ..	0.086 ..	0.152 ..	0.092 ..	0.076 ..
200° F. ..	0.086 ..	0.152 ..	0.092 ..	0.076 ..

Under conditions of boundary lubrication, lubricating oils form adsorbed layers on the surfaces, which they wet, and the stronger and more viscous the adsorbed layers are, the more is wear reduced. Friction tests carried out by Hutchison and the author<sup>5</sup> on fixed and mineral oils under conditions of boundary lubrication have shown that fatty oils possess those properties to a greater extent than mineral oils (Table IV.). Other properties, however, such as volatility, oxidation, and emulsification do not always allow of the use of fixed oils. Compounded oils and oils containing a small proportion of fatty acid are also superior to mineral oils in reducing friction and forming viscous adsorbed layers.

The influence of surface temperature of sliding metals and the effect which it has on lubrication is also of importance and has been investigated by Bowden and Ridler.<sup>6</sup> Using the sliding metals as thermocouples by rotating a ring of one metal against a loaded specimen of another metal,

and making the point of contact a thermocouple, the surface temperature of several pairs of sliding metals were determined, when it was found that rise in surface temperature was directly proportional to the speed and the load, except near the melting temperature of the metal with the lower melting-point. Constantan sliding on mild steel had a surface temperature over 500° C. when lubricated, and over 1,000° C. without lubrication. The results of such experiments indicated that under conditions of boundary lubrication adsorbed films are continually being destroyed locally and being repaired during sliding, and that one of the chief causes for breaking down is the high temperature produced by the surface areas which are in sliding contact. Under such conditions, therefore, lubricants with a high volatility and graphite with a high melting-point should give satisfactory results.

**Running-in and Polished Surfaces.**—It has been suggested that the running-in of a bearing is connected with the formation of a strong adsorbed film of lubricant, and that in the absence of running-in it might be impossible to form such a film. Running-in also produces initial wear by the removal of high spots and surface roughness, then the production of a polished surface, harder and more wear-resistant than the original surface. This surface layer was first shown by Beilby<sup>7</sup> to be an amorphous layer formed over the structure of the metal, and recent investigations have confirmed this view. In building up this layer, oil is probably absorbed with it and adds to its fluidity. Work by Finch and Whitmore<sup>8</sup> on the graphoid layer on bearing surfaces has shown that a white metal disc polished by running-in with a mild steel disc and lubricated with oil, causes graphite particles to be absorbed into the amorphous layer. Invisible oxide films formed on polished surface layers produced by running-in may also influence the coefficient of friction to a large extent. This is most noticeable under light loads, and slow speeds giving light metallic contact, as under heavier loads and high speeds oxide films are not strong enough to prevent contact.

**Cylinder Wear.**—The problem of cylinder wear both in automobile and heavy oil engines is one which has received considerable attention and has helped to contribute to a better understanding of the nature of wear. Such wear, which results in piston slap, loss of power, and increased oil consumption, was for a long period considered to be due to deficient lubrication, dilution of the lubricating oil by petrol, or to abrasives in the lubricating oil. The research work of the Institution of Automobile Engineers, first published in 1933, showed that the components of reciprocating wear in internal combustion engine cylinders were corrosion and abrasion. The wear which takes place in starting up from cold is very heavy in comparison with the wear which takes place during running. Delayed warming up in starting, particularly if accompanied by poor lubrication, causes the increased wear as a result of water and acids (formic, nitric, oxalic and sulphuric) formed by the combustion of the fuel condensing on the cylinder walls at low temperatures and causing corrosion of the cylinder bore and piston rings.

The abrasive effect which takes place in engines running for long periods at high temperatures is confined to the area of the piston rings and is greatest opposite the top ring. It is usually associated with the presence of abrasive materials, dust, silica, and metallic oxides; piston rings with too little clearance; the surface conditions of cylinder bores and piston rings; and the conditions of cylinder lubrication. Cylinder wear is therefore a combination of chemical and mechanical factors in which the chemical factor predominates and is best counteracted by the use of hard corrosion-resisting materials, together with adequate and proper lubrication, if such wear is to be substantially reduced.

<sup>6</sup> F. P. Bowden and K. E. W. Ridler. *Proc. Royal Soc., Series A*, 1936, vol. 154, pp. 640-656.

<sup>7</sup> G. Beilby. "Aggregation and Flow of Solids" (McMillan and Co., Ltd., London), 1921.

<sup>8</sup> G. I. Finch and E. J. Whitmore. *Engineering*, 1935, vol. 146, p. 91.

<sup>5</sup> J. W. Donaldson and D. Hutchison. *J. Soc. Chem. Indus.*, 1933, vol. 52, pp. 424T-429T.

**Wear Oxidation.**—Some iron and steel structures and machine parts show evidences of reddish brown films or dust which lead to a type of wear known as wear oxidation or oxidation wear. Analysis or X-ray examination of those films or dust show them to consist in the case of steels of iron oxides or in the case of alloy steels of mixed oxides. This phenomenon, although mostly found with ferrous metals, may also occur with non-ferrous metals and alloys.

Polished surfaces in sliding contact or rolling with a slight slip between the surfaces show oxidation wear if the intensity of the surface pressure is below that which leads to the removal of metallic particles on a large scale. It also takes place in parts attached to each other by means intended to prevent relative movement, but where movement actually occurs to a minute extent. This latter type of oxidation wear is sometimes known as fretting corrosion. Oxidation wear is most noticeable in ball or roller bearings, between the leaves of laminated springs, and in motor-car springs and shackle pins, and fretting corrosion in such parts as hubs keyed on or shrunk on to shafts, in plates and sections bolted together, and in steel rotating discs on gudgeon pins, where all such parts are subjected to oscillating or alternating stresses or slight relative movement.

Investigations on oxidation wear have been carried out by many investigators using wear-testing machines of the Amsler or similar type. Fink,<sup>9</sup> using discs of tyre steel, found with rolling friction and 1% slip a loss of weight ranging from 0.12 to 0.20 grms. when the tests were made in air. Test specimens became coated with an oxide film which adhered to the specimens until a certain thickness was obtained, when it began to fall off. When the experiments were carried out in an nitrogen atmosphere in order to exclude oxygen, no measurable wear was found, and the sliding surface remained bright.

Rosenberg and Jordan,<sup>10</sup> investigating the effect of oxygen-free atmospheres on the wear of a hypo-eutectoid, a eutectoid, and a hyper-eutectoid carbon steel found that the loss in weight did not vary greatly when the tests were made in air, nitrogen or hydrogen, and it was concluded that in testing with the two latter gases oxygen had to be completely removed. It was also found that, when these steels were hardened and subsequently tempered at low temperature, the rates of wear were comparatively low, while tempering above certain temperatures the rates of wear were extremely high. In each case, wearing surfaces were smooth and were covered with a thin oxide film. Further tests by Fink<sup>11</sup> also referred to the difficulty of obtaining oxygen-free nitrogen. It was also considered that in the presence of oxygen, oxides are formed at the reactive, distorted portion of the metallic lattice and in time lead to the formation of an oxide film which causes increased friction and subsequent oxidation wear, fine oxide particles being removed by mechanical abrasion.

Recent oxidation wear experiments carried out by Matthew<sup>12</sup> confirm the results of these previous investigators. In this investigation, two polished specimens of stainless steel were placed in sliding contact under slight load, first in oxygen and then in nitrogen, the sliding contact between the surfaces taking place in a gas-tight cell. The resulting wear products were carefully examined, and in the first case the wear debris was found to be composed of 90% black metallic oxide, while in the second case, where wear was negligible, the wear debris was a fine amorphous powder. The amorphous nature of the powder was confirmed by an X-ray examination of its structure. As the protective oxide film on stainless steel is extremely thin, about  $8 \text{ in.} \times 10^{-8} \text{ in.}$  thick, the experiments indicated that under the action of continuous wear, exposed stainless steel surfaces oxidised at a considerable speed.

Recent work carried out at the National Physical Laboratory by Tomlinson, Thorpe and Gough<sup>13</sup> on the

fretting corrosion of surfaces in closely fitting contact and when subjected to vibrations, have shown that the corrosion which takes place is of a mechanical rather than a chemical character. Vibration or alternating surface stress alone causes no action, but it is shown that some surface slip effectively causes corrosion even if reduced to the order of molecular dimensions, and has been found to occur without exception whatever the condition of the surfaces. Lubricants modify but do not prevent action. In Table V are given some of the results obtained when tests were made with slip. Soft materials in general tend to seize, and harder materials to produce corrosion or oxide debris. Comparative tests of different pairs of metals show differences in the resistance offered to corrosive action, but no pair of metals show freedom from such action. The amount of corrosion or wear taking place does not appear to depend on the intensity of normal pressure, but only on the occurrence of contact. The oxide debris formed is usually red, but under certain conditions it may become black. A discussion of the mechanism of the phenomenon is given in which the idea of ordinary mechanical abrasion is rejected, and a process of molecular attrition possibly closely associated with fatigue suggested.

TABLE V.  
EXPERIMENTAL RESULTS OF FRETTING CORROSION OF CLOSELY FITTING SURFACES WITH SLIP (TOMLINSON, THORPE AND GOUGH.)

Nature of Surfaces.	Surface Condition.	Duration of Test Hours.	Pressure Between Contact Surfaces, Lb./Sq. In.	Results of Examination of Surfaces.
Hardened and tempered tool steel.	Clean	1	6,000	Marked evidence of seizing, also oxide debris.
	Clean	24	6,000	Similar.
	Oiled	1	6,000	Slight corrosion; no oxide debris.
	Oiled	24	4,000	Similar. Considerable corrosion in places; oxide debris present.
SStainless Steel	Clean	24	6,000	Marked seizure of surfaces; oxide debris present.
	Clean	1	6,000	Evidence of seizing and oxide debris.
	Oiled	24	4,000	Evidence of seizing, but no oxide debris.
	Oiled	24	4,000	Considerable oxide debris. Surface adhered and badly corroded. First 24 hours' run did not produce oxide debris; both surfaces slightly seized.
Stainless steels against hardened and tempered tool steel.	Oiled	24	4,000	After second 24 hours, surfaces were corroded and pitted; oxide debris present.
	Clean	1	6,000	Small amount of oxide debris several seized patches on both materials.
Mild Steel	Clean	24	6,000	Surfaces corroded and seized; oxide debris present.
	Oiled	24	4,000	Very little corrosion; no oxide debris.
Brass against hardened and tempered tool steel.	Clean	24	6,000	Both materials corroded; yellow and red debris formed.
	Oiled	24	4,000	Both materials slightly corroded; yellow and red debris in places.

**Seizure of Surfaces.**—Two smooth, chemically clean, unlubricated surfaces when pressed or rubbed together tend to seize or cohere. Since seizure or surface cohesion has been shown to be largely independent of temperature and to be entirely a function of the type of metals involved, it would appear to depend on the forces of molecular attraction acting at the interface of the opposing surfaces. With a view to determining, firstly, the frictional forces operating between various wearing surfaces, and then, secondly, the nature of seizure, an extensive investigation has been carried out by Matthew.<sup>12</sup>

For those experiments an apparatus was designed in which the fixed specimen was mounted on a spring system with a natural frequency much above the frequency of the oscillations recorded, and this specimen was connected to a special pressure-resisting element coupled with a cathode-ray oscillograph through a Wheatstone bridge and amplifier

<sup>9</sup> M. Fink. *Amer. Soc. Steel Treating*, 1930, vol. 18, pp. 204-212.

<sup>10</sup> S. J. Rosenberg and L. Jordan. *Jour. of Research, Nat. Bureau of Standards*, 1934, vol. 13, pp. 267-280.

<sup>11</sup> M. Fink. *Amer. Soc. Steel Treating*, 1935, vol. 23, pp. 598-613.

<sup>12</sup> T. U. Matthew. *J. South African Inst. Eng.*, 1940, vol. 38, pp. 229-258.

<sup>13</sup> C. A. Tomlinson, P. L. Thorpe and H. J. Gough. *Proc. Inst. Mech. Eng.*, 1939, vol. 141, pp. 223-249.



circuit, so that every change in the friction forces between the two wearing surfaces could be determined visually on a screen or photographically on a moving film. The stationary specimen and its holder were surrounded by a pool of mercury into which dipped a gas-tight container fixed to the moving specimen, so that the tests could be carried out in various atmospheres. Values obtained for the coefficient of dry-sliding friction of various metals with this apparatus are given in Table VI.

To obtain more accurate data a second apparatus was constructed, consisting of a spring mounting for the lower specimen as before, but using a piezo-electric quartz crystal for the recording element. Where the first apparatus at its lowest speed gave a maximum film record length of 12 in. per inch of specimen surface traversed, the second apparatus recorded on 100 ft. of film per inch of specimen length. Ragged fluctuations recorded by the first apparatus were resolved by the second apparatus into a consistent series of obvious seizures, followed by shear, which led to the conclusions and wear between surfaces in sliding contact resulted from seize-shear action at the points of contact.

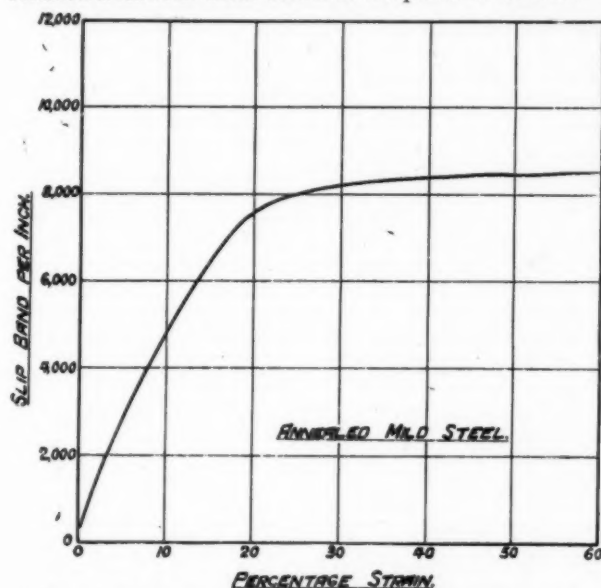


Fig. 1.—Relation between slip-bands developed and percentage strain (Matthew).

Plastic metals, such as soft iron, low carbon steels, aluminium, lead and brass were found to seize readily on themselves and on similar single-phase metals, while hard metals, such as high-tensile steels, nitrided steels, high-duty cast irons and metal complexes with crystal structures containing hard and soft constituents, as in bearing alloys, were much more resistant to seizure on themselves and on other metals. It was also found in experiments with mild steel that limitations were imposed on seizure by slip planes. In Fig. 1, which shows the relation between slip bands developed and percentage strain, in annealed mild steel, it is seen that the number of slip bands per inch increases very quickly at first up to a plastic strain of between 15 and 20%, after which little further increase takes place. Those results led to further tests conducted on colloidal graphite surfaces which showed that seizure-shear did not take place in such surfaces which are known to have their slip planes parallel to the exposed surface. It was also shown that seizure did not take place on compressed fibre surfaces owing to the self-lubricating nature of these surfaces. Self-lubricating surfaces, however, were found to cause rapid loss on steel surfaces by oxidation wear and polishing action.

**Conclusions.**—Research investigation carried out on the various factors involved in the process of wear show that lubrication and the nature of the oil films formed have an

important effect on the wear of sliding surfaces. The rise of surface temperature of sliding metals at the point of contact is directly proportional to the speed and load, and may be as high as the melting-point of the most fusible metal. Lubrication affects sliding contact temperatures.

TABLE VI  
COEFFICIENTS OF DRY SLIDING FRICTION (MATTHEW).

Metals in Contact.		Mean Coefficient of Friction (Dry).
Top.	Bottom.	Average.
Mild Steel	Mild Steel	0.65
0.5% C Steel	0.5% C Steel	0.72
Tool Steel	Tool Steel	0.85
Brass	Brass	0.55
Aluminium	Aluminium	0.88
Mild Steel	Aluminium	0.73

Initial wear which takes place during the running-in of surfaces depends on the degree of surface roughness left as the result of machining operations, and "run-in" surfaces consist of an amorphous layer formed gradually from metallic particles. Cylinder wear has two aspects, a mechanical or physical aspect resulting from sliding contact of the piston and rings up and down the bore of the cylinder, and a chemical or corrosive aspect arising from combustion of fuel in the cylinder. Oxide films exist on all sliding surfaces and influence wear, while oxidation wear occurs by oxide films being continually removed. Seizure which takes place between absolutely clean surfaces moving in contact at ordinary temperature is caused by continual seize-shear action, and this seize-shear action is limited by slip-planes occurring in the metal.

#### Wear-Resisting Materials

The knowledge regarding the various factors in metallic wear which are obtained from the results of wear resistance tests and from research investigations dealing with the various aspects of wear mechanism is important in developing and selecting materials to resist wear from abrasion, corrosion or erosion, oxidation or seizure. The properties of metals and alloys which are involved in wear resistance include hardness, capacity for work-hardening, resistance to oxidation, and structure.

Wear resistance tests on metals have shown (Tables I and II) that the Brinell and Vickers hardnesses of alloys often bear no definite relationship to their wear-resisting properties. Two materials with practically the same hardness may often have quite different rates of wear. This is noticeable when considering cast irons for cylinder wear. In general, however, alloys with a high hardness are more resistant to abrasive wear than those with lower or more normal hardnesses, so that the development of steels and cast irons of high hardness or the surface treatment of steels and cast irons to produce a high degree of hardness is of importance. The retention of hardness at high temperatures is also important, particularly when the wear of cutting tools is considered. At the point of cutting contact of such tools, high-sliding speeds produce intensive loading temperatures approaching the melting-point of the more fusible material. For such tools, best results as against wear are obtained with cemented metallic carbides, such as tungsten carbide or with Stellite or similar materials which retain their hardness well at such temperatures.

For the production of hard surfaces to resist wear, carburising or case-hardening has long been established, and during recent years carburising practice has greatly improved. Other processes, including the nitriding of alloy steels, the induction hardening of the outer and inner surfaces of steel and cast-iron parts, the flame-hardening of outer surfaces, hard-surfacing with low- and high-alloy steels, non-ferrous alloys and tungsten and boron carbides, and hard chromium plating have also been developed with the production of hardened surfaces of a much higher degree than those produced by carburising. In Fig. 2 are shown the Vickers hardness produced by case-hardening, nitriding, and induction hardening of steel, together with the relative depths of hardening produced by those three methods of surface hardening, while in Table VII are given

the surface hardness of steels flame-hardened by the Shorter process.

TABLE VII.  
SURFACE HARDNESS OF STEELS HARDENED BY SHORTER PROCESS.

C.	Mn.	Ni.	Cr.	Mo.	Vickers Hardness.
0.46	0.69	—	—	—	783
0.65	0.50	—	—	—	870
0.42	0.71	—	1.05	—	782
0.39	0.56	1.52	1.16	—	770
0.36	0.70	3.34	0.20	—	710
0.39	1.59	—	—	0.31	773
0.36	0.60	—	1.13	0.31	726

Hard-surfacing consists in welding on to the wearing surface of a metal a facing, part, edge, or point of a harder material to resist abrasion. Hard-facing materials are usually (1) low-alloy steels containing either manganese, chromium, nickel, tungsten, molybdenum or vanadium with 0.3 to 0.6% carbon, and alloying elements approximating to 5%; (2) high alloy steels of manganese, cobalt, tungsten or nickel, together with high-chromium, the alloying elements exceeding 10%; (3) non-ferrous alloys of cobalt, chromium and tungsten which have the property of red-hardness; and (4) carbides of boron, tungsten, tantalum or titanium, which have a hardness range between 8.5 and 8.9 on the Moh scale of hardness and which retain their hardness well at elevated temperatures. Alloys of the third group have hardnesses ranging from 440 to 800 Vickers (415 to 650 Brinell). Hard chromium plating, with deposits varying from 0.032 in. or more, and hardnesses up to 1,400 Vickers, 70 to 72 Rockwell C, is used for plating cutting tools, and drills which fail by wear intensified by frictional heat, gauges and jigs, shafts and internal combustion engine cylinders. With regard to the latter, in one particular instance, the cylinder wear of a chromium hardened cylinder bore when tested against an alloy cast iron cylinder liner and a nitrided cylinder liner was found to be 1/70 that of the former and 1/10 that of the latter.

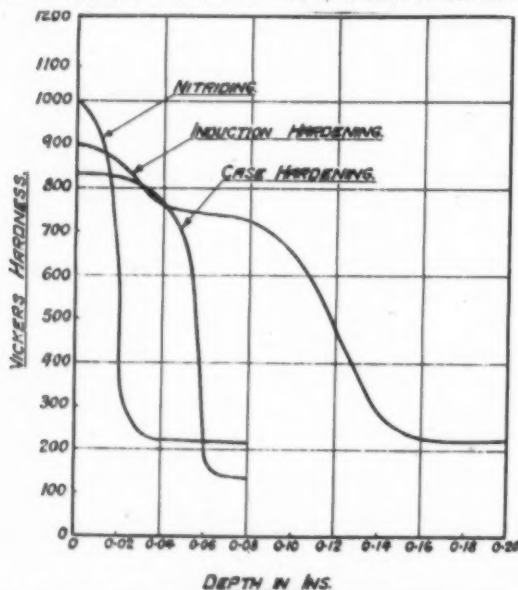


Fig. 2.—Surface hardness and depth of hardness after case-hardening, nitriding, and induction hardening.

Work-hardening of rolling or sliding surfaces also helps to reduce wear. Hadfields' manganese steel, containing 12% manganese, is a well-known example of a steel which develops a very high wear-resisting surface in service, and one which is extensively used on that account in mining work, in excavating work, and in railway work. Increase in surface hardness also occurs in service in carbon steels, such as are used for railway tyres and rails. Tests have shown such steels with Brinell hardnesses of 230 to 250 to increase to 350, hardened steels for automobile gears with original hardnesses of 480 to 500 to increase to 700 to 900, and case-hardened automobile cams of 700 to 800 Brinell hardness to increase to 1,150 to 1,200. High

abrasive loads also produce extremely hard wear-resisting surface layers in nickel-chromium cast irons, such as Ni-hard (3.0% carbon, 4.5% nickel, 1.5% chromium, Brinell hardness 550 to 800), which is used for such applications as rolls for the hot- and cold-rolling of metals, rollers, crusher jaws, parts used in the crushing, grinding and handling of abrasives, pumps handling sand or gravel, and in sand-blasting plant in foundries.

Wear also occurs in certain parts subjected to high temperatures and oxidising conditions, parts such as internal combustion engine valves, scrapers in ore-roasting furnaces, links and hearths in stokers and skid rails for furnaces. For such parts, materials with a high resistance to scaling and the chemical action of hot gases, a high resistance to creep, and a good resistance to repeated impact stress, are necessary, and such properties are best found in heat-resisting steels with high nickel and chromium contents, together with small percentages of tungsten and other elements, and in such non-ferrous alloys as Monel metal and high nickel-copper and nickel-chromium alloys which not only possess good mechanical properties at high temperatures, but also have thin protective oxide films on their exposed surfaces.

The influence of structure in the selection of a metal or alloy to resist wear is of particular interest as regards bearing metals and cast irons. The structure of a good bearing metal is generally regarded as consisting of hard particles or crystals embedded in a soft matrix or ground mass, although as a result of some of the newer bearing metals developed this conception has recently received criticism. Brinell hardness determination on individual crystals in tin-base bearing metals have shown values of 65 and 20 for hard and soft constituents respectively, and of 190 and 75 for similar constituents in sand-cast bronzes. These hardnesses allow of adjustment to the imperfections which occur in rolling and sliding surfaces when such alloys are used for bearing purposes. The low melting points of tin-base bearing metals also do not cause serious break-down in the lubricant. In the case of cast irons, it has been found that better wearing properties are obtained when the graphitic structure is coarse. Pearlitic cast irons have a better wear resistance than cast irons with a sorbitic structure, while austenitic cast irons, such as Ni-Resist and Nicro-silal, whose structure consists of austenitic and graphite, and where chromium is present in small amounts of chromium carbide, have still better wearing properties. Graphite in the surface layers of cast iron is also thought to produce self-lubrication, and it has been suggested that further developments should be made in alloys with self-lubricating work-hardening surfaces for materials to resist metallic wear. Self-lubricating types of bearings introduced during recent years are the porous bronze bearings which are composed of a mixture of powdered metals, copper, tin, zinc and aluminium, compressed together and sintered. Such bearings, which absorb oil readily, and may also contain graphite, are being increasingly used for a variety of purposes.

### North-East Coast Institution of Engineers and Shipbuilders

THE Council of the above Institution has made the following awards:—

*M. C. James Medal.*—Mr. R. W. L. Gawn, R.C.N.C., Superintendent of the Admiralty Experimental Works, Haslar, for his paper on "Roughened Hull Surface."

*Institution Scholarships.*—Harry Kay, of Sunderland, and William Irvine Miller, of Wallsend.

*George Mitchell Harroway Scholarships.*—Frederick Hyde, of Wallsend.

*Weighton Medal.*—Ian Welsh Goodlet, B.Sc.

Awards for papers read before the Student Section to the following:—S. Mathwins Davis, B.Eng., R.C.N.C.; Ian W. Goodlet, B.Sc.; James Dawson, B.Sc.; E. H. Vie, B.Sc.; Wm. Gardner; and W. T. Atkinson, B.Sc.



# A Note on the Relation of Heat Loss and Temperature in Furnaces

By G. O. Taylor, M.S.E., F.Inst.P.I.

*For efficient and economical heating in a furnace it is necessary to limit heat losses and, normally, problems associated with these losses involve complex calculations. In this article the author has simplified the solution of some of these problems by establishing simple laws relating to heat loss, temperature and other factors which permit results sufficiently accurate for practical purposes.*

**A** QUICK method for evaluating the loss of heat from the exterior of a furnace, or the like, and of estimating the efficiency of heat retention of existing furnace brickwork is often useful. Normally, the solution of such heat loss problems demands the employment of a number of formulæ, but several authorities have prepared nomograms or graphs, from which, by direct reading, the values sought or found can be immediately interpreted without recourse to calculation.

Such graphical solutions, however, are not always readily available; consequently, in the present note, an endeavour is made to reduce calculation to a minimum by establishing simple laws relating heat loss, temperature and other factors. To prepare these laws, recourse was made to figures quoted in literature by manufacturers of refractories and also in the work by Etherington.\* Subsequent verification of the values derived from the simple laws with those given by the nomograms shows that the easily calculated results are sufficiently accurate for most practical purposes.

## Relation Between Heat Loss per Square Foot of Area of Exterior of Furnace and the Temperature of the Exterior.

To derive a basic law relating the heat loss in British Thermal Units (B.Th.U.s) per square foot per hour from the exterior of a furnace with the corresponding surface temperature, a graph was plotted using values derived from trade literature and nomograms.

To produce a straight line, it was necessary to plot the logarithm of the heat loss against the logarithm of the corresponding temperature in °C., when by computation of the slope the following relation was found:—

$$\text{Heat loss of furnace exterior in B.Th.U.s/sq. ft./hr.} = \frac{\text{Temperature of exterior in } ^\circ\text{C.}^{1.687}}{7 \cdot 127}$$

Values were taken in B.Th.U.s and °C., as it is prevalent in this country to quote heat losses more often in B.Th.U.s than in C.H.U.s (Centigrade Heat Units), and temperature more often in °C. than °F.

Since 1 C.H.U. is equivalent to 1.8 B.Th.U.s, and the conversion of °F. into °C. is given by  $\frac{5}{9}(\text{°F.} - 32)$ , the basic relation can be adopted to suit varying units of measurement, as below.

## To Ascertain Heat Loss of Furnace Exterior, Given Exterior Surface Temperature (et).

$$(a) \text{ Heat loss in B.Th.U.s/sq.ft./hr.} = \frac{et \text{ in } ^\circ\text{C.}^{1.687}}{7 \cdot 127} = \left\{ \frac{5}{9}(et \text{ in } ^\circ\text{F.} - 32) \right\}^{1.687} \frac{1.8}{7 \cdot 127}$$

$$(b) \text{ Heat loss in C.H.U.s/sq.ft./hr.} = \frac{et \text{ in } ^\circ\text{C.}^{1.687}}{12 \cdot 83} = \left\{ \frac{5}{9}(et \text{ in } ^\circ\text{F.} - 32) \right\}^{1.687} \frac{1.8}{12 \cdot 83}$$

## To Ascertain Surface Temperature (et) When Heat Loss per Square Foot per Hour is Known

$$(a) \text{ et in } ^\circ\text{C.} = \sqrt[1.687]{(\text{B.Th.U.s emitted/sq. ft./hr.} \times 7 \cdot 127)} = \sqrt[1.687]{(\text{C.H.U.s emitted/sq. ft./hr.} \times 12 \cdot 83)}$$

$$(b) \text{ et in } ^\circ\text{F.} = 1 \cdot 8 \left\{ \sqrt[1.687]{(\text{B.Th.U.s emitted/sq. ft./hr.} \times 7 \cdot 127)} \right\} + 32 = 1 \cdot 8 \left\{ \sqrt[1.687]{(\text{C.H.U.s emitted/sq. ft./hr.} \times 12 \cdot 83)} \right\} + 32$$

## Relation Between Heat Loss per Square Foot of Exterior of Furnace and Wastage of Power or Fuel

From the basic formula it is simple to estimate the wastage of power or fuel equivalent to the heat emitted from the exterior of the furnace:—

$$(a) \text{ Electricity wasted in kwh/sq. ft. of furnace exterior/hr.} = 0 \cdot 000293 \left\{ \frac{(\text{Temp. of exterior in } ^\circ\text{C.})^{1.687}}{7 \cdot 127} \right\}$$

$$(b) \text{ Gas wasted in cubic ft./sq. ft. of furnace exterior/hour} = \frac{\text{Temp. of exterior in } ^\circ\text{C.}^{1.687}}{7 \cdot 127 \times \text{calorific value of gas in B.Th.U.s/cub. ft.}}$$

$$(c) \text{ Oil wasted in lb./sq. ft. of furnace exterior/hour} = \frac{\text{Temp. of exterior in } ^\circ\text{C.}^{1.687}}{7 \cdot 127 \times \text{calorific value of oil in B.Th.U.s/lb.}}$$

Formula (a) is based on 3,411 B.Th.U.s being equivalent to 1 kwh. In the case of formula (b) it is useful to remember that 1 therm is equal to 200 cubic feet of gas having a calorific value of 500 B.Th.U.s per cubic foot. With the formula expressed in terms of B.Th.U.s per cubic foot, account can be taken of the lower calorific values encountered with water gas and producer gas.

In the case of formula (c), it is useful to remember that fuel oil weighs 9 to 10 lb. to the gallon.

## Relation Between Interior and Exterior Furnace Temperatures and Wall Thickness

It is sometimes necessary when examining a furnace to form an opinion on the insulating value of the brickwork courses, or, alternatively, when designing a furnace, to calculate the loss of heat and exterior temperature for a given thickness of furnace wall.

This can conveniently be done by expressing the brickwork in terms of Standard Brick Equivalent, the standard brick being regarded as a normal firebrick having an average thermal conductivity of 10 B.Th.U.s per square foot of area per 1 in. thickness per °F. of temperature difference.

According to Etherington ("Modern Furnace Technology"), heat conduction by a single material can be expressed by the formula  $q = \frac{KA(t^1 - t^2)}{d}$ , where  $q$  is

the heat flow in 1 hour,  $A$  is the area of wall in square feet,  $t^1$  and  $t^2$  the inner and outer temperatures of the wall,  $d$  the thickness of the wall in inches, and  $K$  the quantity of heat transferred in the case of unit wall, 1 ft. square, 1 in. thick, and with a temperature difference equal to 1° C.

\* E. Etherington, "Modern Furnace Technology." Published by Charles Griffin & Co., Ltd.

In the case of any furnace where it is possible to measure the internal and external temperature, this formula can be modified to give by simple calculation the thickness of the wall in terms of Standard Brick Equivalent.

Since  $q$  is the heat flow in 1 hour and  $A$  the area in square feet of the wall through which heat is flowing, for  $q$  can be substituted the expression  $\frac{et^{1.687}}{7.127}$  (where  $et$  is the temperature of the exterior of the furnace in  $^{\circ}\text{C}.$ ), and for  $A$  can be substituted unity, since the heat flow through 1 sq. ft. only is being considered.  $K$  can be substituted by 10, since the mean conductivity of the "standard brick" is regarded as 10 B.Th.U.s per square foot per hour per 1 in. thickness per  $^{\circ}\text{F}.$  of temperature difference.

Since in this country it is the general practice to quote temperature in  $^{\circ}\text{C}.$ , but heat losses more commonly in B.Th.U.s than in C.H.U.s (which should be more correctly used to provide similar units), the formula, when transposed into terms of  $^{\circ}\text{C}.$ , becomes:—

$$\frac{d(et^{1.687})}{7.127} = 10 \{1.8 et + 32\} - (1.8 et + 32)$$

where  $it$  and  $et$  are internal and external furnace temperatures measured in  $^{\circ}\text{C}.$

By simplification the equation becomes:—

$$d = \frac{7.127 (18 it + 320) - (18 et + 320)}{et^{1.687}}$$

$$d = \frac{7.127 (18 it - 18 et)}{et^{1.687}}$$

$$d = \frac{128.3 it - 128.3 et}{et^{1.687}} \therefore d = \frac{128.3 (it - et)}{et^{1.687}}$$

where for known internal and external temperatures of the furnace in  $^{\circ}\text{C}.$   $d$  is the thickness of wall in inches of Standard Brick Equivalent.

To illustrate the ease with which the various formulae can be applied, let it be assumed that in the examination of an electric resistor furnace it has been found that when the internal temperature is  $1,200^{\circ}\text{C}.$ , the external temperature is  $112^{\circ}\text{C}.$  It is required to find the heat and power losses of the exterior of the furnace, and also to form an opinion on the heat retention properties of the existing brickwork courses.

#### Heat Losses

Heat loss in B.Th.U.s/sq. ft./hr. from exterior—

$$\begin{aligned} &= \frac{(\text{Temp. of exterior in } ^{\circ}\text{C.})^{1.687}}{7.127} \\ &= \frac{112^{1.687}}{7.127} \end{aligned}$$

$$\begin{aligned} \text{By logs} &= (2.0492 \times 1.687) - 0.8529 \\ &= 2.6041 \end{aligned}$$

Heat in B.Th.U.s/sq. ft./hr. (Antilog 2.6041)—  
= 400 B.Th.U.s (approx.)

#### Power Loss

The power loss in kwh/sq. ft./hr.

$$\begin{aligned} &= \frac{0.000293 \{ (112)^{1.687} \}}{7.127} \\ &= 0.1172 \text{ kwh/sq. ft./hr.} \end{aligned}$$

Thickness of Wall ( $d$ ):—

$$\begin{aligned} d &= \frac{128.3 (it - et)}{et^{1.687}} \\ &= \frac{128.3 (1200 - 112)}{112^{1.687}} \\ &= \frac{139,590}{2,850} \end{aligned}$$

Thickness of Wall ( $d$ ):—

$$= \text{approx. 49 in. (S.B.E.)}$$

To form an opinion on the heat retention properties of the brickwork from the calculated wall thickness in Standard Brick Equivalent inches requires some experience in types of brickwork construction, but it can fairly quickly be arrived at.

The first consideration is the face course in the furnace. In most cases this will be one of the refractories classed generally as firebrick, silica brick, chrome brick, or magnesite brick.

In "Modern Furnace Technology" Etherington gives a useful table showing the variation in value either side of unity of these refractories at various temperatures, unity being the "Standard brick" of 10 B.Th.U.s thermal conductivity. This table is partially reproduced below:—

Temp. $^{\circ}\text{C}.$	Fireclay Brick.	Silica Brick.	Chrome Brick.	Magnesite Brick.
200	1.4	1.25	1.0	0.25
400	1.2	1.0	0.95	0.28
600	1.1	0.9	0.90	0.34
800	1.0	0.8	0.85	0.26
1,000	0.95	0.7	0.85	0.28
1,200	0.90	0.65	0.85	0.40
1,400	0.90	0.65	0.85	0.40
1,600	0.85	0.60	0.85	0.41

Now if measurement has shown that the approximate thickness of the furnace lining is 18 in., and it is known that the face course is, for example, of silica brick, the analysis would proceed as follows.

Considering, first, the silica brick. To give a reasonable hot-face temperature for the insulating courses, the thickness of the silica refractory is not likely to be less than 9 in. At  $1,200^{\circ}\text{C}.$  the value assigned to silica brick is 0.65, therefore the Standard Brick Equivalent inches accounted for the refractory is about  $9 \times 0.65$ , or approximately 6 in.

The total value of the wall is 49 in. S.B.E.: therefore, the remaining 9 in. of actual thickness (presumably of insulation) must have a value of 49—6, or 43 in. S.B.E.—i.e., 1 in. of insulation is equivalent to 5 in. of S.B.E. But 1 in. of S.B.E. has a thermal conductivity of 10 B.Th.U.s; therefore, the conductivity of 1 in. of insulation can be assigned the approximate value (at an interior furnace temperature of  $1,200^{\circ}\text{C}.$ ) of 2 B.Th.U.s per square foot per hour per  $^{\circ}\text{F}.$  per inch of thickness.

This is a good value for brick insulation, and if it is desired to reduce the heat losses further when the furnace is rebricked, consideration would have to be given to various forms of insulation to produce a 9-in. course having a conductivity of less than 2 B.Th.U.s per square foot per hour per  $^{\circ}\text{F}.$  per inch thickness.

#### Calculation of Heat Loss and External Temperature for a Designed Wall Thickness

If, in designing a furnace or other heat appliance of like nature, the type of wall is known, and also the internal working temperature, then the external temperature and heat loss can be deduced as follows:—

First express the wall in terms of Standard Brick Equivalent inches and estimate the overall heat conductivity.

10

This will be given by  $\frac{\text{Thickness of wall in S.B.E.}}{10}$ , since one Standard Brick Equivalent inch is equal to the transmission of 10 heat units per square foot per 1 in. thickness per hour per degree of temperature difference.

Then the total heat loss  $X$  in B.Th.U.s per square foot per hour is given by  $X = K$  (Internal temperature  $^{\circ}\text{F}.$  — External temperature  $^{\circ}\text{F}.$ ) where  $K$  is the overall heat conductivity of the wall derived, as explained above.

But the external temperature is not accurately known, and Etherington has shown that, in general, the S.B.E. of the heat loss from the exterior surface can be assumed at a value slightly higher, or lower, than 4 in. for the majority of cases, and that this value should be added to the calculated S.B.E. thickness of the wall for deriving the conductivity, when the external temperature can then be regarded as  $70^{\circ}\text{F}.$  (room temperature).

The formula then becomes :—  
Heat loss in B.Th.U.s/sq. ft./hr.

$$= \left\{ \frac{10}{\text{S.B.E. of wall} + \text{"circa 4"}} \right\} \times \left\{ \frac{\text{Internal temp. } ^\circ\text{F.} - \text{External temp. } ^\circ\text{F.}}{\text{temp. } ^\circ\text{F.}} \right\}$$

Experience shows that it is difficult to decide how much "circa 4" should be added.

Using the nomograms given by Etherington, the following "circa 4" values have been calculated, and by adding the

#### "Circa 4" Values to be Added to Compensate External Temperature Effect

Internal Temperature, °F.	Calculated Wall Thickness in S.B.E. Inches.									
	100 in.	80 in.	60 in.	50 in.	40 in.	30 in.	25 in.	20 in.	15 in.	10 in.
100 (38° C.)	7	7	7	7	7	7	7	7	7	7
500 (260° C.)	7	7	7	7	7	7	7	7	7	7
1,000 (538° C.)	6.3	6.0	5.3	4.9	4.9	4.6	4.4	4.2	3.9	3.7
1,500 (815° C.)	5.5	4.9	4.7	4.7	4.4	4.1	3.9	3.8	3.5	3.0
2,000 (1,093° C.)	4.9	4.8	4.5	4.4	4.1	3.9	3.6	3.4	3.0	2.5
3,000 (1,649° C.)	4.6	4.4	4.1	3.9	3.6	3.3	3.1	2.9	2.6	2.2
3,500 (1,927° C.)	4.4	4.1	3.9	3.7	3.5	3.1	2.9	2.7	2.4	2.1

appropriate value nearest to the interior temperature and S.B.E. wall thickness under consideration, results coinciding very closely with the values given in the nomograms can be calculated.

Considering a typical example : if a furnace has been designed to have a 30-in. S.B.E. wall and an internal temperature of 2,500° F., then the heat loss will be :—

$$\begin{aligned} \text{Heat loss/sq. ft./hr.} &= \left( \frac{10}{30 + 3.6} \right) \times (2,500 - 70) \\ &= 0.29 (2430) \\ &= 705 \text{ B.Th.U.s} \\ \text{External temp. } ^\circ\text{C.} &= 1.687 \sqrt{(705 \times 7.127)} \\ &= 156.5^\circ\text{C.} \end{aligned}$$

The simple formulae given in this note can be used whenever diagrams are not available, and will, since they are based largely on Etherington's nomograms, closely reproduce the results given therein. The latter formulae are, however, only applicable to solid walls, and must not be used in cases where the walls may contain air gaps or cavities.

## Oil-Retaining Bronze Bearings

*In view of the attention now being directed to various types of bearings, reference to oil-retaining composite bearings is appropriate, and perma's ibl: Loads and speeds of revolution of such a bearing are given.*

ONE of the most important advantages of the use of oil-retaining bronze bearings is their value in bearings which are almost inaccessible for normal lubrication. These bearings contain sufficient lubricant to maintain efficient running conditions for years without attention. These special self-lubricating bearings are of particular value for electric motors, fans, pumps, crushers, conveyers, screens, machine tools and much other equipment, and considerable interest is associated with the maximum loads and speeds of revolution that are permissible with these bearings.

A typical composition is that of the British Round Brook Bearing Co., Ltd., which consists of 88% copper, 7.9% tin, 1.4% graphite, and 0.9% of other materials. This bearing metal is made by high die pressing the pure electrolytic metals in the finely divided condition. Consequently, the bronze is porous because of the micro-spaces between the particles, and up to 30% by volume of oil is absorbed, although the metal is almost as hard as if cast, with a crushing strength, for example, of about 70,000 lb. per sq. in.

When the pressure or temperature varies in the bearing the oil in the metal exudes, giving highly efficient lubrication, which is continuous, often for the entire life of the bearing. Under enormous pressure, however, the oil is squeezed out, and consequently there is theoretically a maximum in the shape of bearing pressure and shaft velocity above which the bearings will not function because of the lack of oil.

The firm have prepared a chart for the determination of permissible load and allowable speeds for various shaft diameters based upon an empirical formula determined as the result of long experience; that is,  $PV = 50,000$  where P is the load or pressure in pounds per square inch on the actual bearing area, and V the shaft velocity in feet per second.

These curves relate to seven standard shafts between the sizes  $\frac{1}{2}$  in. and 2 in. diameter, and in general, as already

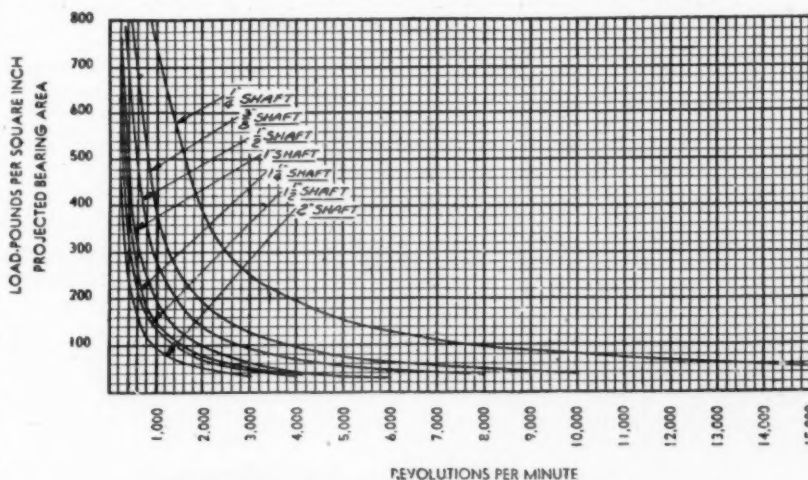


Chart for general determination of permissible loads and allowable speeds for various standard shafting diameters when using these bearings.

indicated, if the pressure in the bearing in pounds per square inch multiplied by the velocity exceeds a factor of 50,000, then additional lubrication must be given. Obviously, there are few bearings in which such extremely severe conditions exist. Thus, for example, with low pressure and small shafts, speeds up to 20,000–25,000 revs. per min. can be used, and there are quite a number of such installations running. Also with slow-speed shafts enormous bearing pressures can be taken without difficulty, such as 2,000 lb. per sq. in., with a shaft velocity of 25 ft. per sec. When the shaft velocity is 50–100 ft. per sec., a high bearing pressure up to 500 lb. per sq. in. is allowed, and so on, while the chart covers limits of up to 800 lb. per sq. in. bearing pressure and 15,000 revs. per min.

It will be understood of course that such a chart relates to normal average good conditions as regards heat dissipation from the bearing surrounding atmospheric temperature and normal dust content in the atmosphere. In general, these oil-retaining bronze bearings will carry a load equal to well lubricated cast bronze, and such bearings can be obtained with a length of  $1\frac{1}{2}$  times the diameter, while hundreds of standard intermediate sizes are available.



# A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

**T**HIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the second of the series, is presented a summary of the results of investigations on connecting rods, gudgeon pins and wrist pins.

The parts examined represent an extensive range of the various types of enemy aircraft which have fallen into the hands of the R.A.F. since the beginning of the war.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts had been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions due to our blockade on enemy procedure and selection of materials was kept in mind.

Attention was given chiefly to engine parts, but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations.

For the purpose of this report, components of the same type from different aircraft have been considered

together and the main features summarised. A section to be published later will contain a complete list of all the individual parts examined by the Committee, classified under the respective engines or type of aircraft, and for fuller details the individual reports should be consulted.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

## Section III.—Connecting Rods

**T**HE nine samples examined included seven types of German engine and one Italian, two of the samples being in the nature of duplicates for checking purposes.

### Types of Rod

Three of the engines (B.M.W. 132K, Bramo Fafnir 323P, and Fiat A. 80 R.C. 41) were of the radial type, involving a "master" and auxiliary rods. In the other engines (Jumo 211A, B 1, F 1, and Mercedes-Benz D.B. 601A and D.B. 601N) there were two types of rod, one having a single "big end" and the other a double "big end," and two rods working on one pin, as seen in Fig. 4(a). The types illustrated in Figs. 1 to 6 were as follows:—

Fig. 1.—Jumo 211A (Report No. 4).

Fig. 2.—Jumo 211.F.1 (Report No. 115).

Fig. 3.—B.M.W. 132K (Report No. 14).

Fig. 4.—Mercedes-Benz D.B. 601A (Report No. 21).

Fig. 5.—Bramo Fafnir 323P (Reports Nos. 41 and 42).

Fig. 6.—Fiat A. 80R.C.41 (Report No. 81)

Fig. 1a.—Jumo 211A, double "big-end" rod.



Fig. 1b.—Jumo 211A, single "big-end" rod.

Fig. 2a.—Jumo 211.F.1, double "big-end" rod.

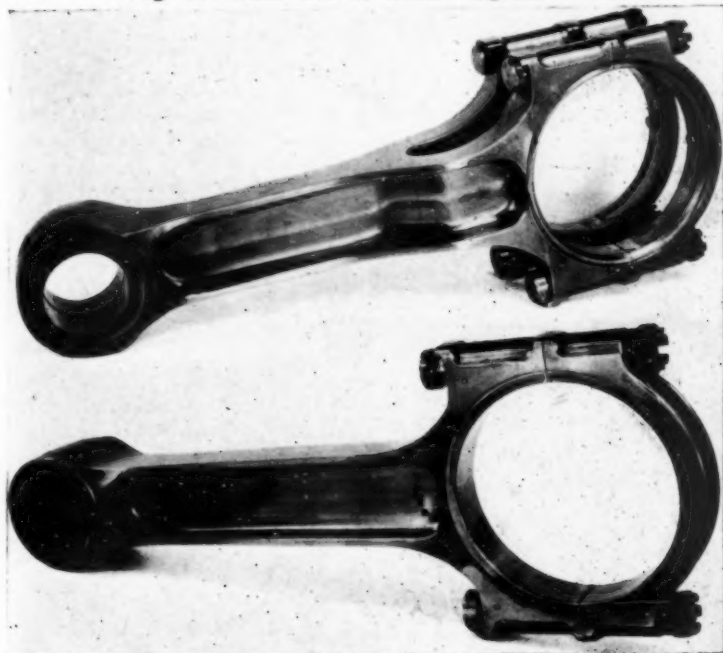


Fig. 2b.—Jumo 211.F.1, single "big-end" rod.



Fig. 3.—B.M.W. 132K.

Fig. 4a.—Mercedes-Benz D.B. 601A, two rods on one pin.

Fig. 4b (centre).—Mercedes-Benz D.B. 601A, single "big-end" rod.  
Fig. 4c.—Mercedes-Benz D.B. 601A, double "big-end" rod.

### Analyses

As regards composition, steels were either 2/2 nickel-chromium-molybdenum steel or 1 to 1½ chromium-molybdenum, except in the Italian engine, where the materials were of the 2½ nickel-chromium and 2½% nickel-chromium-molybdenum types. One later type of Jumo engine (Report 115) was found to be more of the 2½/1½ nickel-chromium type with both molybdenum and vanadium.

The bolts were of similar composition to the rods, except in the Mercedes-Benz D.B. 601A and the later Jumo 211.F.1 engines. In the former the bolts were made from a low carbon 4½% nickel-chromium steel, case carburised, while the latter approximated to 2½% chromium-molybdenum. The nuts were essentially chromium-molybdenum steels with the exception of one 1½% nickel-chromium steel.

Other auxiliary parts consisted of a stud for locking purposes of 3½% nickel-chromium steel, nitrided wrist pins of 2½% chromium-molybdenum steel, roller race and roller bearing of high-carbon-chromium steel, and bearing shell of low-carbon steel lined with lead bronze. Details of compositions and mechanical tests are given in Table I.

### Mechanical Tests

In general, the maximum stress values were between 65 and 75 tons per sq. in., although the later Jumo 211.F.1 single rod, already mentioned, showed a tensile strength of 83 tons per sq. in. The Fiat rod and one German rod were in the region of 60 tons per sq. in. The hardnesses on the surfaces showed

Fig. 5a.—Bramo Fafnir 323P, master rod.

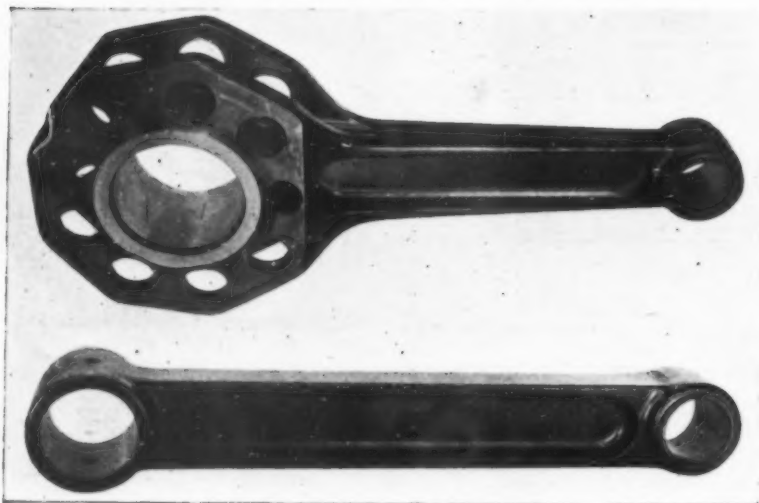


Fig. 5b.—Bramo Fafnir 323P, auxiliary rod.

appreciable variation, and on one of the Fiat rods a zone of lower tensile strength gave only 53.9 tons per sq. in. The ductilities accompanying the tensile strength were all of a very high standard, e.g., 20% elongation and upwards for 65 to 75 tons per sq. in., with Izod values generally above 50 ft.-lb., and in some cases up to 80 ft.-lb.

#### Manufacture of Steel

Cleanliness was in most cases of a very high standard, and no marked deterioration in the quality of the later Jumo engine materials was observed. Of the 33 samples analysed for sulphur, 16 gave values below 0.01% and 11 others below 0.02%.

It is concluded from the general analyses, cleanliness and results of gas analyses, that the steels are essentially basic electric steels. The rods of Reports Nos. 86 and 14 were of less clean steel, and these may have been made of acid O.H. steel.

Fig. 7a.—Flow structure of Jumo 211A single big-end rod.

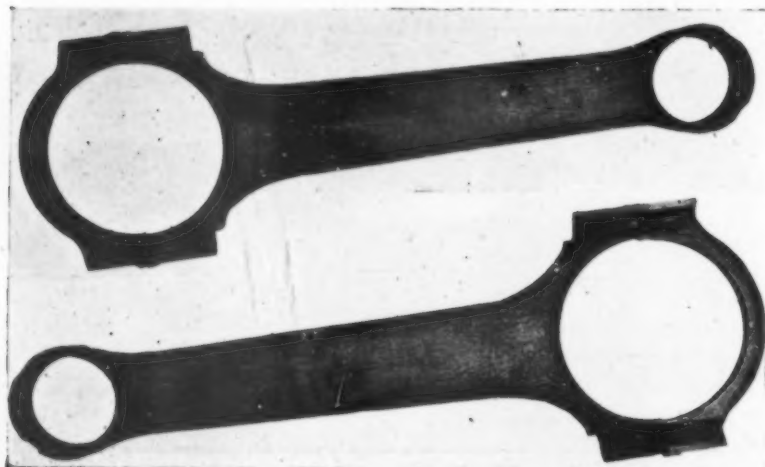


Fig. 7b.—Flow structure of Jumo 211A double big-end rod.

#### Manufacture of Rods

Metallographic examination indicated that all the rods had been produced by forging or drop forging methods, giving a good type of "flow structure," as desired for maximum strength and toughness. Macros of Reports Nos. 4, 14, 21, 41, 42 and 81 are illustrated in Figs. 7 to 11. Nuts and bolts were generally machined from bar, but in No. 81 the bolts had been made from up-ended bar.

#### Heat Treatment

Microstructure in all cases showed satisfactory response to hardening and tempering treatment. (See Figs. 12 to 16.) In the Bramo Fafnir sample the master rod was found to have been surface hardened all over by nitriding treatment (see Fig. 15). Photomicrographs of the double and master rods only have been included.

Fig. 6a.—Fiat A. 80R.C.41, master rod.

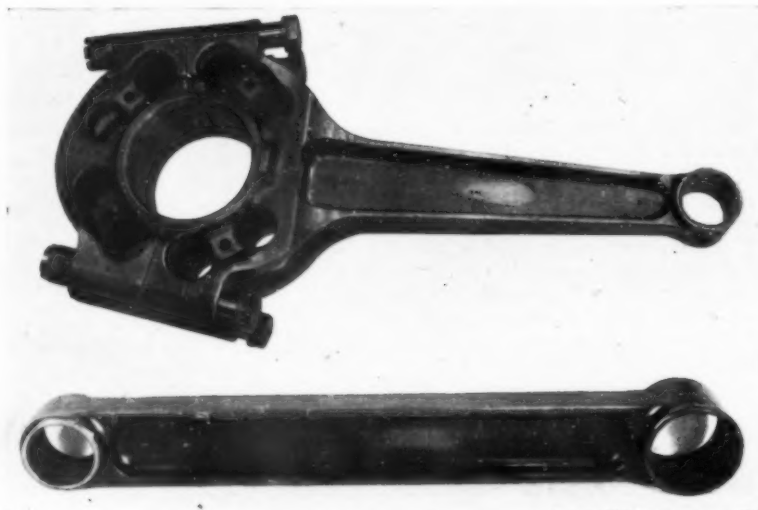


Fig. 6b.—Fiat A. 80R.C.41, auxiliary rod.

#### Surface Finish

A high standard had clearly been aimed at throughout, both as regards accuracy of fit, and condition of surface.

#### Accessories

These are dealt with under the headings of Wrist Pins and Bearings. Details of bolts and nuts are given in Table I.

#### General Remarks

The chief features learned from these rods are:—

- (a) Preference for two types of composition, 2/2 nickel-chromium-molybdenum and 1½ chromium-molybdenum steel.
- (b) High standard of cleanliness with resulting good mechanical properties—i.e., high ductility and impact for 65 to 75 tons per sq. in. condition.



Fig. 8a.—Flow structure of B.M.W 132K master rod.



Fig. 8b.—Flow structure of B.M.W 132K auxiliary rod.



(c) That no deterioration as regards quality had occurred in the later Jumo 211.F.1 engine parts (Nos. 115 and 126) belonging to planes shot down in September and November, 1941. In the case of No. 115, a newer composition brought about by the addition of vanadium was found.

The relatively high copper content of No. 115 is interesting, but no deleterious effects seem to have resulted.

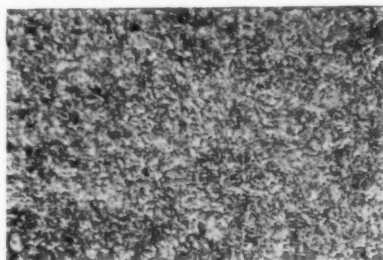


Fig. 16.—Microstructure of Fiat A. 80 R.C.41 master rod.  $\times 200$ .

Fig. 9a.—Flow structure of Mercedes-Benz D.B. 601A single big-end rod.

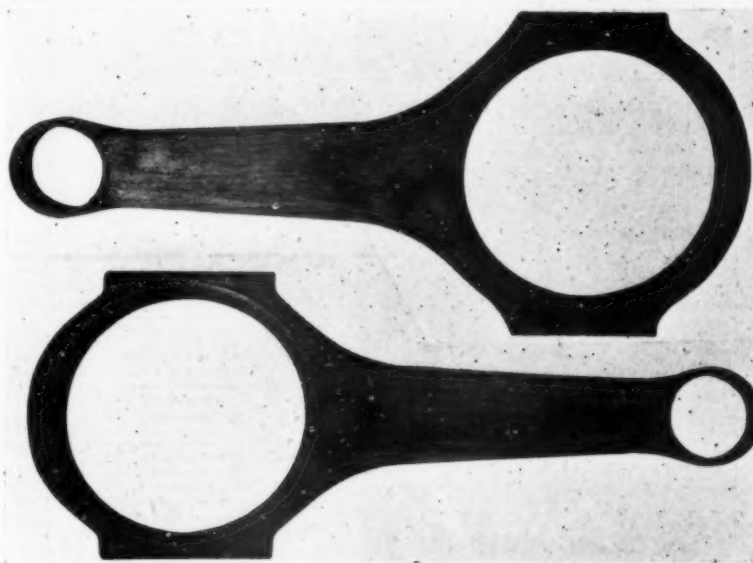


Fig. 9b.—Flow structure of Mercedes-Benz B.D. 601A double big-end rod.

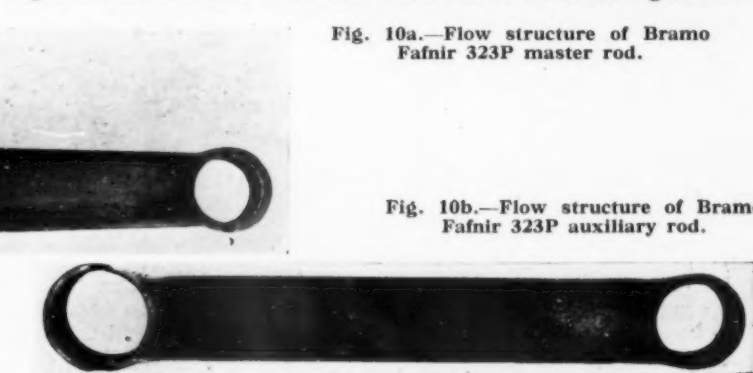


Fig. 10a.—Flow structure of Bramo Fafnir 323P master rod.

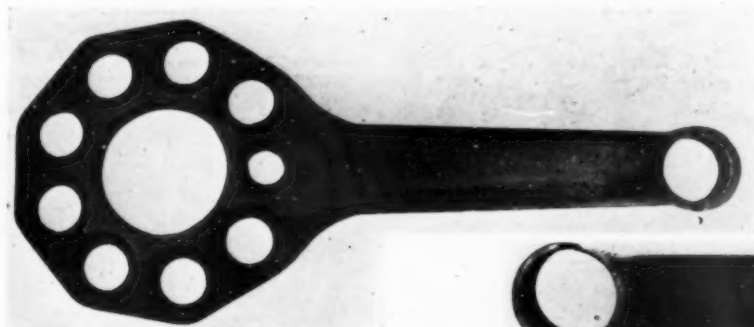


Fig. 10b.—Flow structure of Bramo Fafnir 323P auxiliary rod.



Fig. 11a.—Flow structure of Fiat A.80R.C.41 master rod.

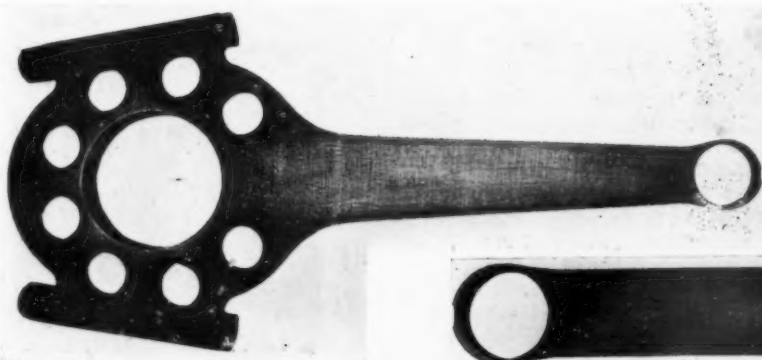


Fig. 11b.—Flow structure of Fiat A.80R.C.41 auxiliary rod.



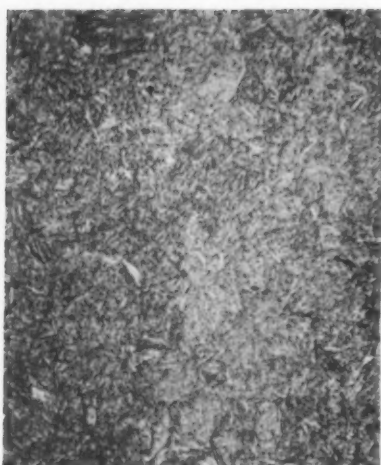


Fig. 12.—Microstructure of Jumo 211A double big-end rod. x 200.

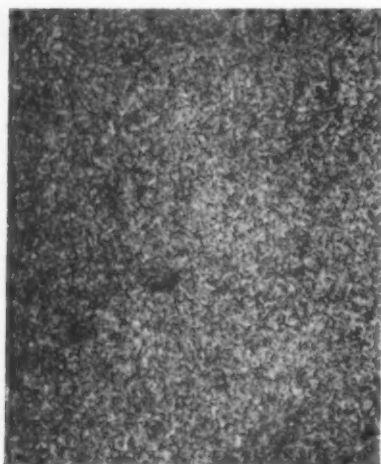


Fig. 13.—Microstructure of B.M.W. 132K master rod. x 200.

TABLE I.—CHEMICAL COMPOSITION AND MECHANICAL

Report No.		C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu.
4	Jumo 211A (Heinkel 111H.)										
	Single big-end rod	0.28	0.24	0.57	0.003	0.015	1.76	1.94	0.25	Nil	0.15
	Double big-end rod	0.35	0.26	0.42	0.005	0.009	1.89	1.95	0.33	Nil	0.08
	Single big-end bolt	0.32	0.26	0.47	0.007	0.018	2.26	1.91	0.27	0.10	0.08
	Double big-end bolt	0.31	0.24	0.39	0.014	0.019	2.31	1.84	0.39	Nil	0.11
	Single big-end nut	0.40	0.28	0.63	0.026	0.020	0.09	1.18	0.21	Nil	—
	Double big-end nut	0.55	0.24	0.59	0.016	0.016	0.11	0.99	0.24	Nil	0.14
	Stud from big-end of double rod	0.32	0.30	0.57	—	—	3.47	0.96	0.06	Nil	—
14	B.M.W. 132K.										
	Master rod	0.42	0.28	0.69	0.340	0.031	0.54	1.27	0.34	Nil	0.11
	Auxiliary rod	0.11	0.26	0.65	0.018	0.015	0.07	1.12	0.19	Nil	0.00
21	Mercedes-Benz D.B. 601A.										
	Double big-end rod	0.33	0.27	0.50	0.007	0.014	0.39	0.99	0.18	Nil	0.15
	Single big-end rod	0.29	0.29	0.63	0.013	0.010	0.27	1.05	0.15	Nil	0.14
	Double big-end bolt (partly carburised)	0.15	0.34	0.40	0.007	0.008	4.31	1.05	0.09	Ni	0.09
	Single big end bolt (partly carburised)	0.13	0.39	0.41	0.007	0.007	4.30	0.95	0.09	Nil	0.11
	Double big-end nut	0.35	0.29	0.75	0.020	0.010	0.05	1.01	0.20	Nil	—
	Single big-end nut	0.33	0.29	0.70	0.009	0.020	0.02	0.86	0.24	Nil	0.11
41 and 42	Bramo Fafnir 323P.										
	Master rod (Nitrided)	0.32	0.27	0.46	0.007	0.008	1.86	1.97	0.35	Trace	0.07
	Auxiliary rod	0.41	0.29	0.60	0.006	0.011	0.40	1.01	0.24	Trace	0.09
81	Fiat A. 80R.C.41.										
	Master rod	0.29	0.29	0.47	0.010	0.008	2.37	0.74	0.06	Nil	0.08
	Articulated rod	0.33	0.28	0.49	0.013	0.007	2.34	0.93	0.17	Nil	0.10
	Master rod bolt	0.30	0.29	0.50	0.019	0.013	2.66	0.75	Trace	Nil	0.10
	Master rod nut	0.40	0.29	0.47	0.018	0.008	1.64	0.69	0.03	Nil	0.10
93	Jumo 211B (1).										
	Double end rod	0.38	0.38	0.52	—	—	2.00	1.90	0.31	N.B.	All
	Single end rod	0.32	0.35	0.38	—	—	2.00	1.90	0.34		
	Double end rod bolt	0.32	0.25	0.48	—	—	2.00	2.00	2.29		
	Double end rod nuts	0.43/0.54	0.31/0.37	0.58/0.72	—	—	0.10/0.47	1.0/1.1	0.17/0.19		
	Single end rod bolt	—	0.25	0.48	—	—	2.0	2.0	0.27		
	Single end rod nut	0.45	0.35	0.65	—	—	0.45	1.1	0.16		
86	Mercedes-Benz D.B. 601N (Messerschmitt 109F.)										
	Rod	0.36	0.28	0.56	0.022	0.017	0.25	0.96	0.15	Trace	0.10
115	Jumo 211.F.1 (Ju. 88).										
	Single Big End Rod	0.34	0.44	0.48	0.014	0.011	1.48	2.48	0.17	0.20	0.22
	Double big-end rod	0.33	0.33	0.39	0.007	0.012	1.65	2.46	0.16	0.14	0.11
	Single big-end bolts	0.31	0.48	0.54	0.011	0.018	0.37	2.19	0.15	0.27	0.22
	Double big-end bolts, Nos. 1, 3, 4.	—	0.34/0.37	0.62/0.65	—	—	0.10/0.11	2.30/2.65	0.19/0.20	Nil	—
	Double big-end bolts, No. 2	—	0.30	0.55	—	—	0.18	2.50	0.21	0.24	—
126	Jumo 211.F.1 (Heinkel 111 H6)										
	Plain rod	0.26	0.30	0.49	0.007	0.008	1.99	1.93	0.14	Nil	0.09

## Section IV.—Gudgeon Pins and Wrist Pins

TEN gudgeon pins and two wrist pins, representing six German engines and one Italian, were examined. Table I summarises the investigations carried out on the gudgeon pins, while Table II similarly deals with wrist pins.

### A.—GUDGEON PINS

#### Visual Examination

The surfaces of the pins were characterised by two or three well-defined brown circumferential markings, composed of a slight deposit—probably of carbon, with several less distinct rings between them (see Figs. 1 and 2). Owing to a shorter length of service the pins from the Mercedes-Benz D.B. 601A and D.B. 601N engines exhibited bright bands. The surfaces of the pins showed a well-lapped finish, which had become scratched in service.

With the exception of the pin from the Mercedes-Benz D.B. 601N engine (Report No. 91), all the pins showed eccentricity of the bore, which varied from one-half to seven-thousandths of an inch with respect to the external diameter. The dimensions are shown in Figs. 3 to 9.

#### Analysis

Six of the pins were made from carburising, three from nitriding, and one from direct-hardening steels. Three of the carburising steels contained 2% nickel, 2% chromium, 1% molybdenum, and the other three contained 1% chromium, 0.2% molybdenum. Two of the nitrided pins were made from 2½% chromium-molybdenum steel, and the other from 1½% nickel, 1½% chromium, 1% molybdenum, and 1% aluminium steel. The uniformly hardened steel

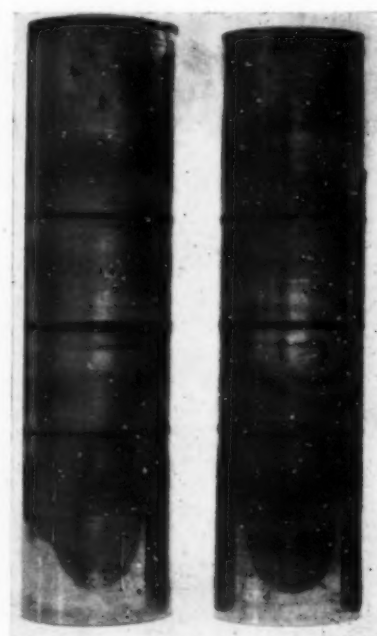


Fig. 1.—Gudgeon pins of Jumo 211A.

## PROPERTIES OF RODS AND AUXILIARY PARTS.

O <sub>2</sub>	H <sub>2</sub>	N <sub>2</sub>	Inherent Grain Size.	Y.P. or 0.5% P.S.	M.S.	El. %.	R.A. %.	Izod Impact.	Brinell Hardness.
0.003	<0.00005	0.015	4 to 6	66.7	72.2	20.0	—	83	364—402
0.002	<0.00005	0.014	6 to 7	66.5	69.5	26.0	—	83	332—364
—	—	—	—	59.4	69.4	8.5	68.5	—	321—340
—	—	—	—	57.1	65.6	8.5	68.5	—	316—321
—	—	—	—	—	—	—	—	—	332—336
—	—	—	—	—	—	—	—	—	262—266
—	—	—	—	—	—	—	—	—	286
0.005	0.00006	0.003	6	62.2	75.1	17.0	47.5	49, 41	321—364
0.003	0.00013	0.010	5 to 6	62.1	66.9	20.0	70	75 estimated	286—306
0.0040	0.00011	0.0109	4 to 5	63.9	70.4	21.5	64.5	71	269—321
0.0028	0.00019	0.0106	3 to 6	55.0	60.7	22.5	71.0	77.5	269—306
0.0012	<0.00005	0.0094	7 to 8	65.0	66.4	21.0	67.5	67 estimated	—
0.0032	0.00012	0.0070	8	64.0	66.5	21.0	68.5	—	—
—	—	—	—	—	—	—	—	—	287—314
—	—	—	—	—	—	—	—	—	282—302
0.0027	0.00013	0.016	6 to 7 Occasional coarse grain	70.4	75.0	20	61.5	49 case core	752—865 DH 358—364 DH
0.0027	0.00014	0.015	6 to 7	67.5	74.5	20	56.5	45 estimated	302—336
0.002	0.0003	0.007	5 to 6	Flange 56.3	61.6	24	60	—	302
0.003	0.0005	0.007	Some No. 4	Big end 45.7	53.9	26	67	73	286—321
0.005	0.0005	0.008	4 to 6	61.8	67.0	190MH	68	—	321—332
—	—	—	4 to 6, some No. 2, Mainly 6, some No. 4.	61.4	66.5	19	63.5	—	293—321
—	—	—	—	—	—	—	—	—	286
—	—	—	—	—	—	—	—	—	388—393
—	—	—	—	—	—	—	—	—	358—363
—	—	—	—	—	—	—	—	—	339—341
—	—	—	—	—	—	—	—	—	304—343
—	—	—	—	—	—	—	—	—	315—317
—	—	—	—	—	—	—	—	—	329—331
—	—	—	4 and some No. 2 and 3.	57.5	64.9	18	—	67	306—309
—	—	—	—	80.1	83.1	19	—	40	387—430
—	—	—	—	66.9	71.6	16.5	—	35	332—364
—	—	—	—	61.5	59.2	22	68.5	—	(1) 315—332
—	—	—	—	52.5	58.0	21	69.5 (No 1 only)	—	(2) 553—280
—	—	—	—	60.9	66.3	21	69.5	—	244—291
—	—	—	—	—	—	—	—	—	306
—	—	—	—	—	—	—	—	—	321—332

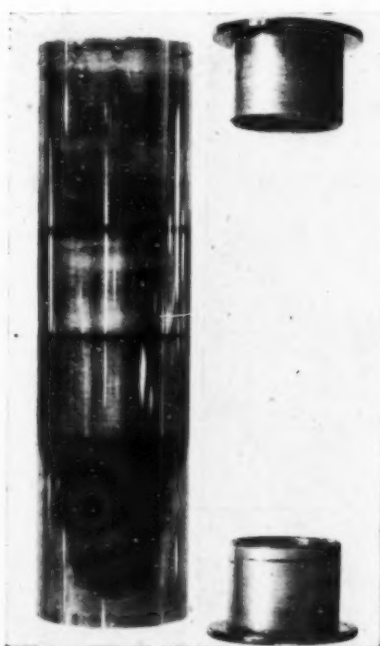


Fig. 2.—Gudgeon pin of Jumo 211F.1 (Engine 334).

contained 0.50% carbon, 1% chromium, and  $\frac{1}{2}$ % molybdenum.

The low sulphur and phosphorus and comparatively high nitrogen contents indicate that all the steels were made by the basic electric-arc process.

#### Grain Size

The grain size of the steels from which the pins were produced varied from medium to fine.

#### Magnetic Etch Test

With the exception of the pin from the Bramo Fafnir 323P engine, all the pins were free from cracks or other defects which would be revealed by magnetic etching. The Bramo Fafnir pin, however, showed 15 longitudinal streaks associated with inclusions, the maximum length being  $\frac{1}{8}$  in.

#### Sulphur Prints

All the pins appeared to be free from segregation.

#### Macroscopical Examination

The macrostructure showed generally a well-defined uniform flow of metal, as typified by Fig. 10.

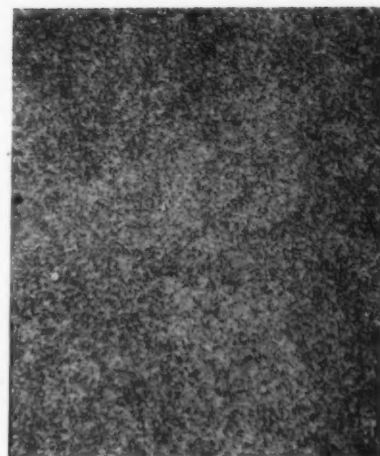


Fig. 14.—Microstructure of Mercedes-Benz D.B. 601A double big-end rod. x 200.

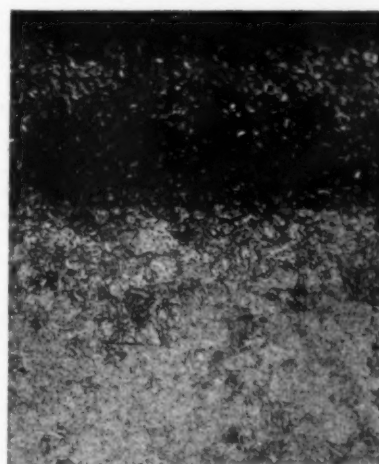


Fig. 15.—Microstructure of Bramo Fafnir 323P master rod. x 100.

#### Hardness Tests

Diagrams and curves showing the surface and depth hardness of the pins are given in Figs. 11 to 22. The pin from the Italian Fiat A. 80R.C.41 engine showed a fairly uniform hardness of 550/571 V.P.N. throughout the section. The carburised pins showed fairly or very uniform surface hardness values, but the hardness of the nitrided samples decreased, or became irregular towards the ends. The hardness of the ends of the pins showed no consistent relationship to the case or bore hardness, and the results are summarised as follows:—

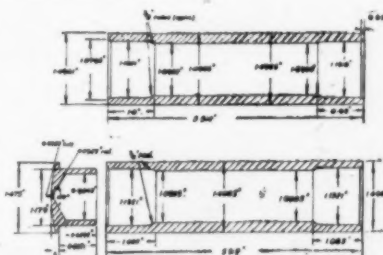


Fig. 3.—Jumo 211A gudgeon pins.





The hardness gradient across the case-hardened pins was fairly regular, but the hardness at the inner surfaces showed no consistent relationship to the outer case or core hardness. The results are summarised as follows:—

Engine.	Type of Case.	Hardness at Inner Surfaces.
Junkers Jumo 211A (1) .....	Carburised	Increased slightly towards bore.
Junkers Jumo 211A (2) .....	Carburised	Increased slightly towards bore.
Junkers Jumo 211F.1 (Engine 334) ..	Carburised	Increased towards bore.
Junkers Jumo 211F.1 (Engine 514) ..	Carburised	Increased towards bore. Gradient similar to that at outer surface.
B.M.W. 132K .....	Nitrided	Increased towards bore. Gradient similar to that at outer surface.
Mercedes-Benz D.B. 601A .....	Nitrided	Slight decrease at bore surface.
Mercedes-Benz D.B. 601N .....	Nitrided	Marked increase at bore surface. Gradient steeper than that at outer surface.
Bramo Fafnir 323P .....	Carburised	Marked decrease at bore surface.

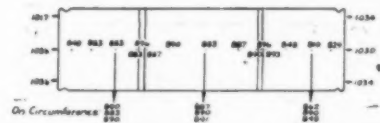


Fig. 13.—Vickers hardness tests, 30 kg. load, on a B.M.W. 132K gudgeon pin.

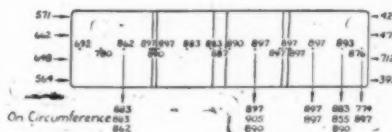


Fig. 14.—Vickers hardness tests, 30 kg. load, on a Mercedes-Benz D.B. 601A gudgeon pin.

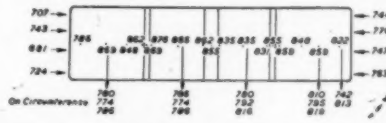


Fig. 15.—Vickers hardness tests, 30 kg. load, on a Mercedes-Benz D.B. 601N gudgeon pin.

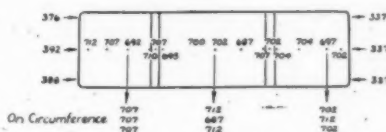


Fig. 16.—Vickers hardness tests, 30 kg. load, on a Bramo Fafnir 323P gudgeon pin.

TABLE I.—GUDGEON PINS.

W.	Ti.	Nitrogen.	Oxygen.	Surface Treatment.	Mechanical Properties (Core).			Diamond Hardness.		Case Depth, In.	McQuaid Ehn Grain Size.
					M.S.	El. %.	R.A. %.	Case.	Core.		
Nil	—	0.013	0.0055	Carburised	—	—	—	700	425	0.043	8
Nil	—	0.023 (case)	—	"	—	—	—	700	425	0.038	8
—	—	0.014	(0.022 (case))	"	—	—	—	—	—	—	—
—	—	0.015	—	Carburised	94.4	21.2	55.1	737—758	434	Outside 0.048 Inside 0.026	5—6 mainly 5
—	—	—	—	"	—	—	—	"	—	—	—
—	—	0.014	—	Carburised	90.0	23.0	61.5	662—742	430	Outside 0.032 Inside 0.026	2—5 Mainly 4
Nil	Trace	0.012	—	Nitrided	81.0	19.0	60.0	800—800	380	Outside 0.016 Inside 0.017	5—6
Nil	Trace	0.012	0.008	Nitrided	78.5	23	58.8	800	370	0.021	5—6
Nil	—	0.009	0.008	Nitrided	80.0	21.2	63.5	774—876	370	Outside 0.022 Inside 0.015	5—6
Nil	0.01	0.012	0.0035	Carburised	91.9	19.0	59	700	410	0.028	2—6 Mainly 5
Nil	—	0.010	0.003	Uniformly hardened	—	—	—	550—571	—	—	3—5 Mainly 4

TABLE II.—WRIST PINS.

W.	Ti.	Nitrogen.	Oxygen.	Surface Treatment.	Mechanical Properties (Core).			Diamond Hardness.		Case Depth, In.	McQuaid Ehn Grain Size.
					M.S.	El. %.	R.A. %.	Case.	Core.		
—	—	0.010	0.0016	Cyanided	—	—	—	869—876	383	0.02 to 0.03	5 to 6
—	—	0.010	0.0034	Nitrided	—	—	—	946—966	321—331	0.015	6
Nil	Trace	0.012	0.003	Uniformly hardened	—	—	—	550—570	—	—	4—6 Mainly 5

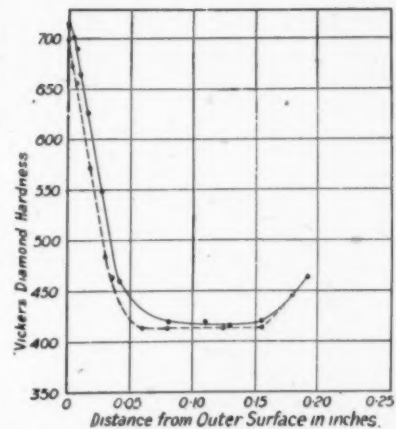


Fig. 17.—Depth-hardness curves of two Jumo 211A gudgeon pins.

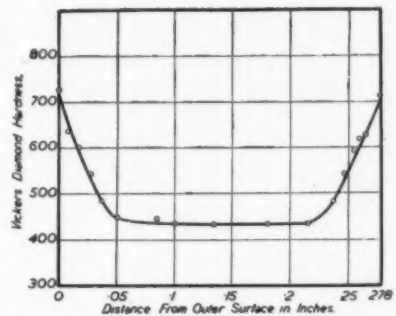


Fig. 18.—Depth-hardness curve of a Jumo 211F.1 (Engine 514) gudgeon pin.

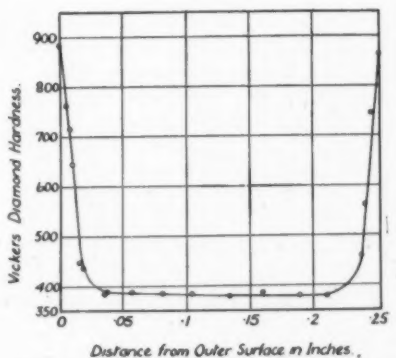


Fig. 19.—Depth-hardness curve of a B.M.W. 132K gudgeon pin.

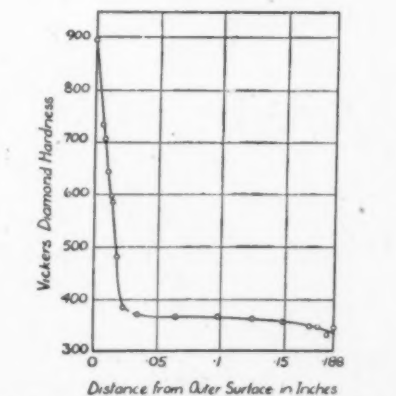


Fig. 20.—Depth-hardness curve of a Mercedes-Benz D.B. 601A gudgeon pin.

inclusions consisted of sulphides and silicate streaks up to 0.020 in. in length, but in the pin from the Bramo Fafnir 323P engine inclusion streaks up to  $\frac{1}{16}$  in. were found.

(b) *Structure*.—The following observations were made:—

Engine.	Structure.
Junkers Jumo 211A .....	Fine martensitic case with some free carbide
Junkers Jumo 211.F.1 (Engine 554) .....	Core slightly coarse and acicular.
Junkers Jumo 211.F.1 (Engine 334) .....	Similar to above but no free carbide in case
B.M.W. 132K .....	Case fairly coarse acicular structure with marked nitride and carbide network. Core, fine sorbite.
Mercedes-Benz D.B. 601A .....	Case showed coarse acicular structure with marked carbide and nitride network. Case brittle. Core, fine sorbite.
Mercedes-Benz D.B. 601N .....	Similar to D.B. 601A but carbide and nitride network only slight.
Bramo Fafnir 323P .....	Generally fine structure with some free carbide. Inner face markedly decarburised.
Italian Fiat A. 80R.C.41 .....	Slightly banded structure; dense sorbite having mottled appearance.

Figs. 23 and 24 illustrate the structures of two of the pins examined.

### B.—WRIST PINS

Only three wrist pins were examined, one from a B.M.W. 132K engine, one from a Bramo Fafnir 323 type, and a third from the Italian Fiat A. 80R.C.41 engine. The results are summarised in Table II.

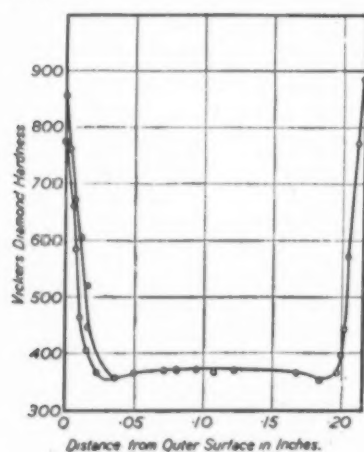


Fig. 21.—Depth-hardness curve of a Mercedes-Benz D.B. 601N gudgeon pin.

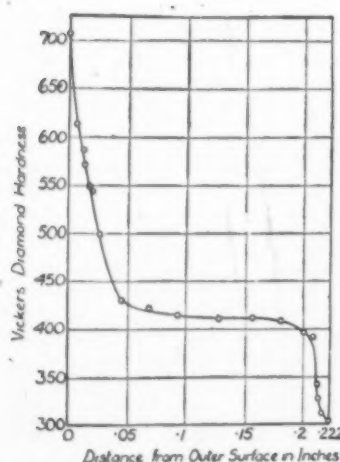


Fig. 22.—Depth-hardness curve of Bramo Fafnir 323P gudgeon pin.

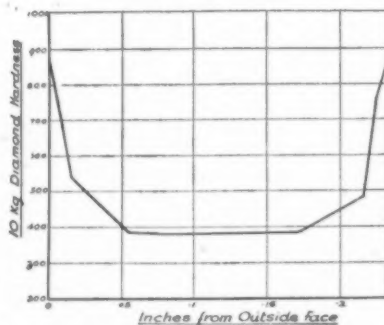


Fig. 27.—Diamond hardness across section of wrist pin of B.M.W. 132K.

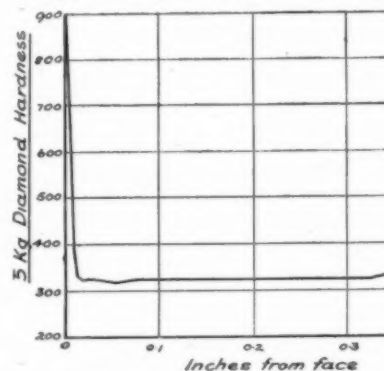


Fig. 28.—Diamond hardness across section of wrist pin of Bramo Fafnir 323P.

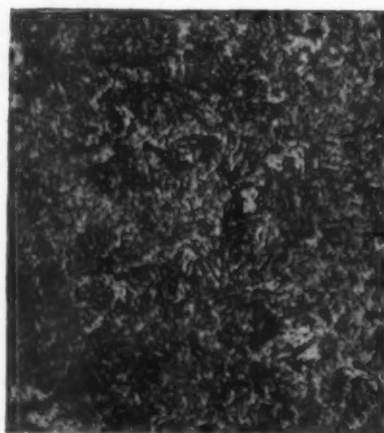


Fig. 23.—Core structure of Jumo 211A gudgeon pin. x 300.

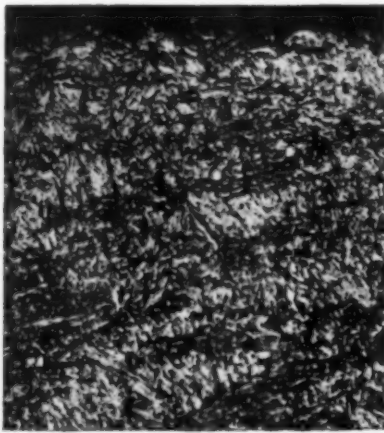


Fig. 24.—Structure of Mercedes-Benz D.B. 601N gudgeon pin.

### Appearance

The surface finish of each showed a smooth lapped appearance, whilst on the non-bearing surfaces of the German pins there was a dark-brown deposit. Two examples are illustrated in Figs. 25 and 26.

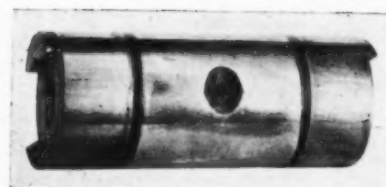


Fig. 25.—Wrist pin of Bramo Fafnir 323P.



Fig. 26.—Wrist pin of Fiat A. 80R.C.41.

treatment, and was of uniform hardness throughout—i.e., 550/570 D.H.

### Sulphur Print and Macro Examination

As was to be expected from the sulphur contents of the steel—viz., 0.004 and 0.005% for the B.M.W. 132K and Bramo Fafnir 323P engines, respectively, and 0.008% for the Fiat



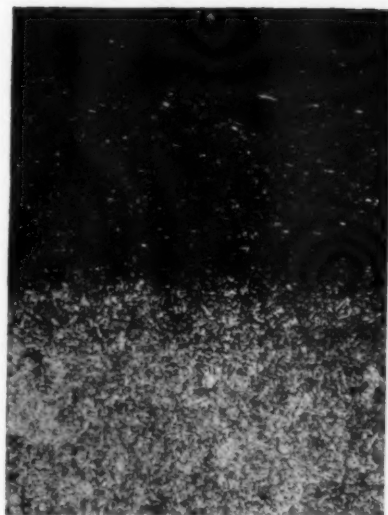


Fig. 29.—Structure of B.M.W. 132K wrist pin. x 100.

A. 80R.C.41,—the sulphur prints on a longitudinal section of each showed very little in the way of sulphide markings. Macro-examination presented no unusual features.

#### Micro Examination and Grain Size

The following inclusion counts (Fox method) were recorded on the German pins:—

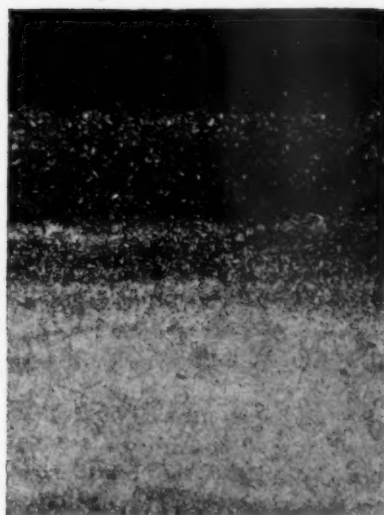


Fig. 30.—Structure of Bramo Fafnir wrist pin. x 100.

B.M.W. 132K	..	..	38
Bramo Fafnir 323P	..	..	33

In all the steels examined the cleanliness was below British Standards. The core structures were sorbitic in all three instances.

Examination near the surface of the German pins confirmed that case hardening has been carried out, but showed that whilst the B.M.W. 132K

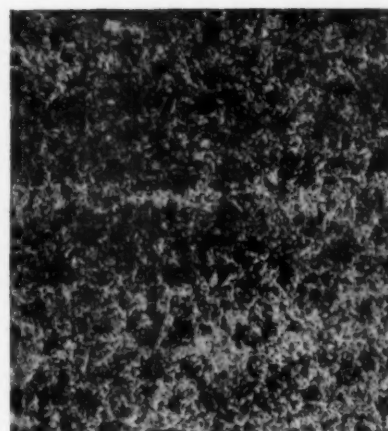


Fig. 31.—Structure of Flat A. 80R.C.41 wrist pin. x 300.

pin had been subjected to a cyaniding treatment the other pin (Bramo Fafnir 323P) had been nitrided. The former was cyanided both on the outside and the core, but the Bramo Fafnir 323P pin was nitrided on the outer surface only. The B.M.W. 132K presented a reasonably fine structure with a rather prominent network on the core case, whilst in the Bramo Fafnir 323P the structure of the case was generally uniform. (Figs. 29 to 31.)

*Cylinders and cylinder liners, valves and valve springs will be considered in the next issue.*

## Atmosphere Control in the Heat-Treatment of Aluminium Products

*The effect of furnace atmosphere on aluminium alloys subjected to prolonged heating is considered as a result of tests.*

CERTAIN aluminium alloys involve prolonged heating to obtain equilibrium conditions, and in studies on these alloys it has been noticed that furnace atmospheres have some effect on the results obtained. In order to determine this effect tests have been made in which 24S alloy sheet was heated at 495°–500° C. in various atmospheres, both dry and moist. Heating was continued for 20 hours, to exaggerate any effects. These were judged by microscopic examination and tensile tests on the heat-treated samples as compared with the same material heat-treated in a fused sodium-nitrate bath.

The results given by Stroup\* indicate that no harmful effects were obtained on the tensile properties by prolonged heat-treatment of 24S-T sheet in a number of atmospheres, which included

helium, hydrogen, dry or moist nitrogen, natural gas, dry oxygen, dry air, moist carbon dioxide, and moist air containing 26% carbon dioxide, or treated with Alorco protective compound. The tensile properties obtained from the use of these atmospheres were as good as those obtained from a fused nitrate bath. On the other hand, water vapour, sulphur dioxide and ammonia produced harmful effects on tensile properties when used as atmospheres for heat-treating. Similarly, moist air or moist oxygen and dry air containing a mere trace of sulphur dioxide produced low properties. This suggests that both oxygen (or air) and moisture must be present to have a detrimental effect as moist nitrogen and moist carbon dioxide had no such effect. The effect of sulphur dioxide present in dry air is shown by the fact that while dry air, free from sulphur dioxide, had no effect on tensile strength and elongation;

the presence of 0.0002% of sulphur dioxide caused a decrease of 3% in the tensile strength and 27% in the elongation, while the effects of 0.0007% of sulphur dioxide in dry air were a reduction of 15% in the tensile strength and 68% in the elongation. The presence of 3.4% water vapour in air caused a reduction of 25% in tensile strength and 77% in elongation.

With moisture the effect increased as the moisture content of the air increased, but a certain amount of moisture could be tolerated. Thinner sheet suffered more in the same time than thicker sheet. The attack by moisture was more noticeable in alloys containing magnesium than on those that did not contain magnesium. Cast alloys were affected by furnace atmospheres to a smaller extent than sheet products.

Observations indicated that the presence of 26% carbon dioxide prevented the effect of moist air, and it was concluded that the addition of 33% or more of natural gas combustion products to air, maintained throughout the heat-treating period, constituted a safe atmosphere. Where combustion products alone are used as the furnace atmosphere and the source of heat, it is essential that they be cooled to the permitted temperature range for the particular alloy that is being heat-treated.

\* P. T. Stroup, A.S.M. preprint, 1941/1942, pp. 207–220.

## Lead-Containing Aluminium-Magnesium Alloys

THE use of lead to confer free-cutting properties on certain alloys is well known. The object of a recent investigation\* was to determine to what extent lead would confer these properties on the aluminium and magnesium type of alloys. With this in view a survey was made of the phase diagram of the whole of the aluminium-magnesium-lead system, and of the production, technological, mechanical and corrosion properties of aluminium-base aluminium-magnesium-lead alloys.

The Al-Mg-Pb diagram was studied by thermal analysis and microscopic examination. In the first place, the extent of the miscibility gap of the Al-Pb system in the Al-Mg-Pb system was determined and found to extend to about 25% Mg. Beyond 25% Mg, Al-Mg-Pb alloys were found to disintegrate more or less rapidly, depending on composition, in contact with air. Alloys exhibiting this behaviour were found in the region between 25% and 50% Mg; they cover a very much wider range of composition in the binary Mg-Pb system. The disintegration is due to the occurrence of the intermetallic phase  $Mg_2Pb$ . The section between  $Al_2Mg_3$  and  $Mg_2Pb$  was found to be quasi-binary of a simple eutectic type, the eutectic containing about 45%  $Al_2Mg_3$ , and melting at 439° C.

In the region Mg- $Al_2Mg_3$ - $Mg_2Pb$  the direction of equilibrium curves and the phase boundaries at room temperature were determined. Alloys in this region consist of three phases: *S* (double saturated Mg-rich solid solution), *S'* (Pb-containing  $Al_2Mg_3$ -solid solution), and  $Mg_2Pb$ , the three phases forming a ternary eutectic which contains 50% Mg, 16% Al, and 35% Pb, and which melts at 405° C.

The region of commercially suitable emulsion-type alloys in the aluminium corner of the phase diagram was determined. Examination of the structure of the alloys showed that Al-Mg alloys are able to retain up to 3.0% Pb in a uniformly distributed disperse form. The Mg content of these alloys is limited to a maximum of 10%, in order to avoid formation of the unstable  $Mg_2Pb$  phase.

Alloying experiments showed that aluminium is able to dissolve 13% lead at 950° C. In preparing Al-Mg-Pb alloys, the aluminium was melted and heated to 850° C., when the magnesium was added, after which the crucible was removed from the furnace. Lead was then added as lead chloride. This is the best way of adding lead as it ensures distribution of the lead throughout the melt, while at the same time the chlorine liberated refines the melt. No other flux is necessary. After complete reduction of the lead chloride and evolution of the chlorine, the melt was poured into pre-warmed moulds, the ingots being fed with molten metal to compensate for shrinkage. In this way Al-Mg-Pb alloys with 7% Mg could be alloyed with up to 2.5% Pb without any segregation of the lead occurring. With care it should be possible to add as much as 3% Pb.

For practical purposes alloys with 7% Mg were selected because of their better ductility as compared with alloys with higher Mg contents, which would have been preferable from the point of view of securing the best free-cutting properties. Alloys of this composition and with lead contents of from 0% to 2.57% were prepared, extruded into rods and their mechanical properties were determined.

Addition of increasing amounts of lead was found to lower the elongation, while the effect on tensile strength and proof stress was insignificant. Even with the maximum lead content, all three were above the values specified for Al-7% Mg alloy.

The cold drawing of rods presented no special difficulties. The lead-containing alloys tended to work-harden less than the Al-7% Mg alloy. Thus, for example, the latter had a tensile strength of 45 kg./mm.<sup>2</sup> (50% reduction), while the

lead-containing alloys (1% and 2.5% Pb, approximately) attain the same tensile strength only after approximately 70% reduction.

The effect of annealing for 6 hours at temperatures of from 100° to 350° C. on the mechanical properties and microstructure of cold-drawn alloys with approximately 1% and 2.5% Pb was also studied. The difference in the lead content had no effect on the response of the alloys to annealing: The elongation increased suddenly on annealing at 250° to 300° C., while the tensile strength and proof stress of even the most severely cold-worked specimens were reduced to their original values at 300° C. Microscopic examination showed that a maximum degree of heterogeneity was obtained by annealing at 250° C. A more uniform distribution of the secondary constituent is obtained by annealing at 300° C., and even more so at 350° C. It is interesting to note that though the latter temperature is above the melting point of lead (327° C.), no detrimental effects were noticed.

Machining tests were made using a turning tool and a parting tool similar in design to those used for free-cutting brass. In general, the use of the parting tool gave much more definite indications as to the effect of different variables on the chip size and shape than did the turning tool.

Free-cutting properties improved with increasing lead content up to about 1.25% Pb. Further additions of lead had comparatively little effect. Increasing amounts of cold work had a detrimental effect on free-machining properties. These can be improved, in some cases even over and above those of the original material, by annealing at 200° to 250° C., or 300° C. Surface finish obtained by machining was very satisfactory where a lubricant was used.

Fatigue tests with smooth and notched specimens showed that the addition of lead had no effect on the fatigue strength, which was the same as that of the Al-7% Mg alloy. Corrosion tests (nine months) in salt spray on alloys containing different amounts of lead showed that their corrosion resistance was practically equal to that of the lead-free Al-Mg alloys. The lead containing free-cutting Al-Mg alloys could be satisfactorily polished and anodised.

## Hard-Facing Worn Parts

THE possibilities of using the electric arc process for depositing hard surfaces on metal parts have not yet been fully exploited. The scope and value of this process in making machine parts more resistant to wear and abrasion, and also to provide cutting edges, however, are gradually being appreciated. The present necessity for reclaiming worn parts of machinery, especially when replacement parts and labour for carrying out the dismantling and erection work involved, is another direction in which this process is finding further useful scope.

Examples of a dozen typical applications of hard facing to engineering tools and other components are given in a recently published booklet. Data on the degree of hardness which can be expected from particular electrodes is also given, together with a classification of the electrodes according to the type of work for which they are suitable. These types ranged from low alloyed electrodes used for reinforcing medium carbon steels and railway tracks, to austenitic alloy electrodes used for building up lips of dredger buckets and manganese steel rail crossings, and also electrodes suitable for giving weld metal of about 600 Brinell hardness. One of the latter type of electrodes is particularly suitable for cutting applications, such as woodworking tools, shearing blades, and dies, where the cutting edge is not subjected to high temperatures, while another deposits a metal similar to high-speed steel and is suitable for tipping mild steel shanks to form lathe tools.

The booklet contains much useful information on the subject and may be obtained gratis from Murex Welding Processes, Ltd. Waltham Cross Herts.

\* H. Bauer, *Aluminium Archiv*, vol. 24, 1939. Abstract from *Light Metals Bulletin*, July 31, 1942.

# The Basic Open-Hearth Process To-Day

## Part II.—Melting Practice

By W. Geary

*In this part the author discusses the training of personnel, and emphasises the need and value of both pure and works research. The making and care of furnace bottoms are considered, together with refractories for this purpose, and their effect on yield and quality. Attention is also given to the selection, preparation and manipulation of charge materials, and to the scheduling of operations.*

**THE Human Factor.**—In the previous article in this series the author gave a brief account of the evolution of the open-hearth furnace, and drew attention to the outstanding features in the design of modern furnaces, in which a measure of standardisation has been reached. The modern furnace, with its auxiliaries, has been placed, from the point of view of engineering construction, substantially on a scientific basis, although there is still some degree of empiricism from the thermal aspect; but when one considers the metallurgical process which is operated in the furnace, one finds that science is playing only a minor part. Because the metallurgical process is supremely important, it follows that science is responsible for only a comparatively small part of the total amount of skill and knowledge needed in steel-making practice.

The late Mr. R. P. Smith, who had a profound knowledge of steel-making, recently said that he thought it was still only 25% science and 75% art. It is as an art that steel-making has developed; while science, in the main, has followed with explanations of observed and already utilised phenomena. Science has explained much, and has been able to erect structures on its foundations. Without the contribution of science the art would not have advanced to its present state: nevertheless, science is still following art, because art is manipulating a high-temperature physical chemistry that science can reason about, but cannot actually contact. Science is making rapid progress in its study of high-temperature phenomena, but in the meantime it stands to the credit of the steel-making personnel that they manipulate their high-temperature process chiefly by means of their acquired skill. The good melter is proud of his art, and of his ability to cope not only with his everyday problems but also with exceptional ones.

The problem facing melting shop personnel to-day is the blending of art with advancing science. Progressive and enlightened melters, with the help of a few dozen men of scientific attainment, have brought the art to its present state. One cannot fail to admire the way in which the pioneer melters laid the foundations of the process. It was done by patience, perseverance and an acutely developed power of observation, served by an ability to draw logical conclusions.

Although science may to-day be 25% of steel-making, it has reached that amount only in comparatively recent years. When a branch of industry once provides a basis for the introduction of scientific methods or control, the subsequent development is likely to be rapid, up to the point where science largely replaces art. It has already been suggested that this stage has not been reached with steel-melting, and we may deduce that the next few years will find science offering increasing possibilities. Science has already made melting an easier task, but it is important to remember that the simplification of the task is not a justification for a reduction in the standard of melting ability. No matter what amount of science is applied to melting practice, there will always be room for, and need for, the expert melter, because only the expert will be capable of dealing promptly and correctly with the exceptional problems that will be met. It is essential, therefore, if the proper value is to be obtained from the contribution of

science that young melters cultivate to the full the traditional skill of their predecessors. Unless this is done, there is a risk that science will be used as a cloak rather than as the aid it should be.

The application of science to the melting shop is a job that normally falls first to the technical workers. It is their duty to keep abreast of scientific development, and to pass on their knowledge. No technical worker can do this unless he fully grasps the melters' work. A young man coming into a melting shop with a technical training must be prepared to put his knowledge if not behind him at least to one side while he makes friends with the melters and learns from them. There remains so much in their art that usually some years are needed to grasp it. When he is really grasping the problem he will find that his teaching starts to fall in line with what he has observed on the furnaces, and only then will he be able to offer a useful contribution to the progress of the shop.

The process of learning through which both technical and furnace workers must go can be speeded up by the use of metallurgical societies, where furnace men and technical men may meet to discuss their problems. Several districts in Great Britain have such societies, and much valuable work is being done. But whether the contact be made in a society or in a works, benefit will always be obtained where understanding and sympathy exist between the workers in the two branches, and where there is a willingness on both sides to see another's point of view and to examine new ideas. The march of scientific progress is inexorable, and the technical and practical workers in our melting shops must march together with it.

### Bottom Building and Maintenance

**(1) Brickwork.**—The last few years have seen a good deal of modification in the construction of bottoms, both in design and in the kind of materials used. Former conventional practice was to build inside the pan a double lining of firebrick and magnesite bricks, the final shape of the brickwork being geometrically similar to that of the pan. The working hearth was then shaped out by the grain refractory. The modern tendency is to modify the shape of the pan and of the brick lining, so as to enable the final contour of the hearth to be attained without making excessively deep pockets of grain refractory.

Regarding materials, the basic refractory brick was formerly always magnesite, but even before the war the use of dolomite bricks, chrome and chrome-magnesite bricks was spreading. Most of the latter materials had the advantage of comparative cheapness (stabilised dolomite bricks in 1938 were less than two-thirds the price of magnesite), and naturally the war has brought about a considerable increase in their use.

A bottom, installed in 1937, was described by E. Drewery<sup>1</sup>, and is illustrated in Fig. 1. The firebrick lining of the pan is shaped roughly to the final contour of the hearth, and magnesite brick is then added. The magnesite has a minimum thickness of 9 in., with a panel 8 ft. square and 12 in. thick at the taphole. The working hearth is of

<sup>1</sup> Symposium on Steelmaking, Iron and Steel Institute Special Report, No. 22, p. 192.



dolomite, fritted in with a little mill scale. It will be seen from the illustration that the monolith is of a fairly uniform thickness.

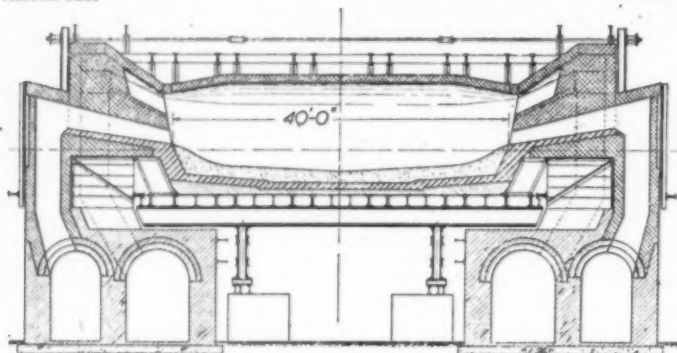


Fig. 1.—Longitudinal section of an 85-ton fixed furnace, showing bottom construction.

The shaped sub-hearth appears to have reached its greatest development in America. W. H. Burr<sup>2</sup> gives an account of a bottom construction designed to reduce the possibility of boils and to lower installation costs. It has a sub-hearth formed roughly to the lines of the finished bottom with a drop of 6 in. from the ends to the tap-hole, and 2 in. from front to back. The hearth consists of 3 in. of insulation, 12½ in. of firebrick cut to contour, a 9-in. soldier course of chrome bricks followed by a 9-in. soldier course of chrome-magnesite bricks, and a 2-in. working hearth of fused grain magnesite.

Chrome or chrome-magnesite bricks are not used for bottom construction in this country to anything like the extent they are used in America, but the use of stabilised dolomite bricks is increasing. Many plants report satisfactory results from this material, and operators have no longer any doubt as to the resistance of the material to hydration.

Although an increasing number of furnaces are being provided with insulated bottoms with, as far as is known, successful results, the practice has not become standard in this country. While it is realised that a bottom must not have such a high thermal conductivity as to necessitate an unduly large heat supply to the furnace, some operators are chary of attempting to suppress all heat passage through the bottom. They fear that if a boil develops while the underlying brickwork is at a high temperature it will not afford the same protection against a breakout. When the working hearth is made of dolomite, as is usual in most of the furnaces in this country, the need for insulation is not felt to the same extent as when magnesite, which has a higher thermal conductivity, is used. Improvement in the resistance of the working hearth to slag or metal attack is being made at the present time, and it seems likely that the use of thin, insulated sub-hearths will follow as a result of increased reliability of the working hearth.

(II) *The Monolith.*—The working hearth is usually made of dead-burned magnesite or dead-burned dolomite. In some cases patent prepared clinkers are used. Although most hearths in this country are of dolomite, certain operators who make a large proportion of deep-drawing steel find that the extra durability of magnesite hearths justifies their higher cost. Magnesite hearths are common in America.

Dolomite hearths may be partly rammed and the remainder burned in, or burned in completely. All operators are not of the same opinion as to the best method of installation, but all are agreed upon the object to be attained. The finished hearth must have a low porosity, to resist penetration, and must be of a composition to resist undue chemical attack by metal or slag.

A notable recent development in America has been the use of plastic chrome or chrome-magnesite pastes. These

are water-setting and are rammed on the brickwork, leaving only a thin layer of magnesite to be burned on. It is claimed that these pastes are cheap to install and extremely resistant to penetration by metal or slag.

Mention must be made of Crespi hearths. This patent system consists of ramming burnt dolomite, ground to the size of "grains of rice and of powder," without the use of tar or fluxing agents. A considerable number of these hearths have been installed, particularly in Latin-European countries, and impartial observers have reported<sup>3</sup> that they are very durable; samples taken from used hearths showing a remarkable freedom from slag penetration.

*Hearth Maintenance.*—Provided a hearth is made of good materials properly installed, its useful life will depend on the care and skill with which it is maintained. Of first importance is the shape. There must be adequate fall towards the tap-hole from all other parts of the hearth to ensure complete drainage. Inadequate drainage inevitably leads to bottom trouble. The passage of the bulk of the slag over the surface of the bottom leaves it in a highly active state, and if any pools of metal are then left in to cool, the iron oxide which forms readily attacks the hearth substance. Perhaps the commonest method by which bottom trouble starts is the developing of soft flat ends, due to a step being allowed to form in the tap-hole. One plant in this country reports excellent results from ensuring adequate drainage by burning away after each tap any suggestion of a step in the tap-hole. Others try to prevent the formation of high steps by driving a tapping bar right through into the furnace, along the bottom of the tap-hole. Whatever method is used, its success or failure will depend on the furnacemanship of the melters. Three good men together will always have a furnace with a bottom sloping nicely to a clean, low tap-hole. One or more backsliders in a team, by "dirty dry-ups" or not splashing-out holes, can cause plenty of bottom trouble for the team.

The maintenance of a good-shaped bottom has an important influence on the yield of ingots. One British plant lowered the tap-hole of all furnaces 9 in. by using less brickwork in the region of the tap-hole. The better slope to the tap-hole enabled the furnaces to empty more quickly and more completely, and the sample passers were encouraged to hold the ladle under the lander until the last drop of mixed slag and metal had run from the furnace. An increased ingot yield of about 2% was credited to the improved drainage.

The best slope for a tap-hole has been the subject of investigations. Apart from the aspect of bottom maintenance, it is well to have a tap-hole that will allow the steel to reach the ladle with a minimum pickup of fine slag inclusions. One investigation,<sup>4</sup> using water and oil to represent metal and slag in a one-tenth scale model of a furnace, showed that a 3° inclination of the metal and slag was obtained by increasing this to 10°.

The author recollects seeing a continental plant in which the 50-ton furnaces had a relatively large hearth area, which made it possible to work with a shallow bath. The tap-holes were kept low, and the bottom at the charging side was level with the middle foreplate; that is to say, there was a straight slope from foreplate to tap-hole. There may be disadvantages in this type of bottom, but at least tapping was quick, draining complete, and bottom repair-time reduced to a minimum.

*Fettling Practice.*—The importance of proper fettling practice cannot be over estimated; it is by far the most important factor in furnace maintenance. It is generally accepted that the best fettling job is done by the dolomite that is put onto a hot, sticky bank. It joins up firmly as a monolith, making a perfect repair and lessening the chance of oxide attack.

<sup>3</sup> Proceedings of the A.I.M.M.E. Open-Hearth Conference, 1941, p. 40.

<sup>4</sup> P. V. Umrikhin, *Metallurg*, 1939, No. 3, pp. 37-46.

<sup>2</sup> W. H. Burr, *Iron and Steel Engineer*, 1940, vol. 17, Jan.

### Steelmaking Materials

(1) *Iron*.—When cold iron is used it is generally not more than about 35% of the charge. It is usually possible to grade the iron to suitable analyses, and even to mix various brands of iron to give a uniform average composition. Some operators have had better outputs when using Stahleisen. Whatever iron is used in cold-metal practice, however, the greatest source of variation in charge composition is the scrap.

The operators of hot-metal furnaces, on the other hand, find that most of their difficulties arise from the hot metal. The symposium on "Steel-making"<sup>5</sup> showed that the amount of hot metal used varied, with one exception, from about 50% to 87½%. To use molten iron in such quantities, and to maintain regularity of melting practice, the production of the iron must be very closely controlled. American operators (who normally do not use more than about 40% hot metal) have laid great stress on this point. Discussing the subject, W. J. Reagan<sup>6</sup> says, "Unquestionably the start of good open-hearth operations is the production of good-quality iron, of constant analysis," and indicates that the usual specification for silicon is about 0.90%, and for sulphur 0.040%, some plants specifying sulphur 0.030%. W. C. Buell, jun.,<sup>7</sup> says: "Low sulphur should be the open-hearth operator's very rigid and principal specification. Low silicon should be the second specification and is one of the greatest aids to the steel-maker's production and cost records." Further, "Silicon in iron is at last being recognised as a major cost problem, which it has ever been. The elimination of excess silicon is one of the most, if not the most, costly items of the furnace phase of steel-making. Excess silicon increases limestone requirements, the heat time is longer, added fuel is required, and furnace maintenance costs are substantially increased." D. L. McBride<sup>8</sup> says that a reduction in silicon of 0.10% is equivalent to a reduction of 30 mins. in heat time. His figures of annual averages over ten years are reproduced in Table I.

TABLE I.  
INFLUENCE OF SILICON VARIATIONS.

Year.	Silicon in Iron, %	Time of Heat, H. M.
1932	1.17	10-21
1931	1.12	11-00
1933	1.12	10-09
1930	1.08	10-39
1934	0.97	10-27
1935	0.95	9-57
1938	0.85	9-27
1936	0.83	9-30
1937	0.79	9-12
1939	0.74	8-45

Obviously, the higher the proportion of hot metal in the charge the greater will be the influence for good or ill of changes in hot-metal quality.

A report has been made<sup>9</sup> giving the results of a series of experiments in which mill scale was added to molten iron running into the ladle from the blast furnaces. About 6½ lb. of scale was used to each 100 lb. of iron, and the silicon was reduced from 0.96% to 0.49%. This iron when used in the open-hearth furnaces permitted a lower lime burden to be used and brought about quicker working, as is shown by Fig. 2.

The removal of sulphur from molten iron by the alkali process has been increasingly practiced during the last few years. Attention was focused on to this aspect of hot metal control by Dr. Colclough's paper<sup>10</sup> in 1937, although it was in use in various countries before that time. Either caustic soda or sodium carbonate may be used for this purpose. The alkali is cheaper in the form of carbonate and therefore soda ash is the reagent commonly employed.

The process may be used, with good effect, over a wide range of sulphur contents.

At one plant where low-silicon, high-sulphur iron is designedly produced, the iron is treated with 5 cwt. of soda ash, 3 cwt. of fluor spar, and 12 cwt. of limestone in a 50-ton ladle. The sulphur is reduced from 0.30% leaving the furnace, to 0.14% leaving the ladle. A further reduction to 0.08% takes place in the mixer. Iron whose sulphur content is comparatively low, but higher than that desired for the open hearth, also may be successfully treated. Fig. 3, taken from a paper by C. L. Labeka and J. L. Walker,<sup>11</sup> shows the results of a careful series of experiments.

Open-hearth operators seem to agree that the use of soda-treated iron does not interfere with furnace operation, nor does it have any detrimental effect on steel quality. Such difficulties as have been experienced with its use in the open hearth are probably related to occasional low-temperature casts, perhaps due to the necessary use of a series of ladles. The use of soda-treated iron appears to cause excessive wear on mixer hearths. Passage of soda-slag into the mixer is suspected to be the cause of this, but no direct evidence has yet come to the author's notice.

*Mixers*.—Most open-hearth plants that operate with a high percentage of hot metal in the charge make use of metal mixers. Where the amount of hot metal is low (about 30%), and the blast-furnace practice reliable, mixers are not often used, but mixer-type transfer cars (Pugh ladles) are used instead.

A mixer is not a cure for all hot-metal ills. It can be relied on to average out, to a degree depending on its holding capacity, the inequalities in the irons from a number of blast furnaces. It cannot, however, in normal operating conditions produce iron of constant composition unless the composition of the iron it receives is also substantially constant. The amount of silicon removed from the iron in a single mixer in an open-hearth shop is usually from 40-60%. With two-mixer practice this percentage is

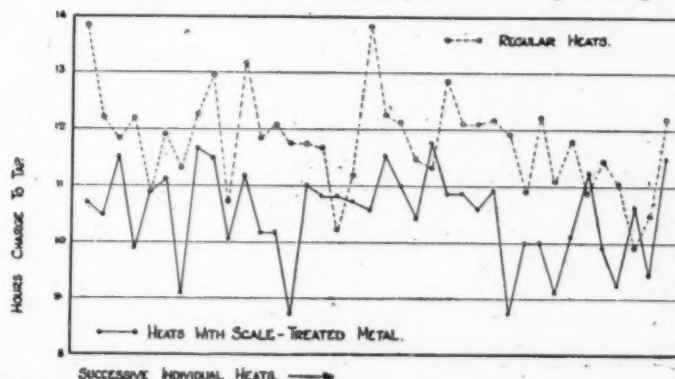


Fig. 2.—Comparison of time of heats showing the effect of using iron of lower silicon content.

increased. The amount of sulphur removed varies considerably, being proportionately greater as the percentage rises in the iron.

(2) *Scrap*.—In any works comprising a melting shop and rolling mill there is about 20-30% of the ingot output returned to the melting shop as bloom crops, saw crops, etc., and frequently the melting shop operates with no other scrap than this. When greater quantities are necessary, recourse must be had to "bought" scrap. The best quality, heavy steel of guaranteed analysis, is usually bought by the makers of acid steel; the remaining qualities, used in basic furnaces, vary from good, heavy steel in charging box sizes to light miscellaneous iron and steel of doubtful origin and quality. The sorting and preparation of scrap is a matter of great importance, and much thought and labour has been given to it. In the last few years a number of new bundling presses have been installed, and

<sup>5</sup> Symposium on Steelmaking, Iron and Steel Institute Special Report, No. 22, p. 469.

<sup>6</sup> W. J. Reagan, *Steel*, 1940, July 22, p. 65.

<sup>7</sup> W. C. Buell, Jr., *Iron and Steel Engineer*, 1941, vol. 18, Mar., No. 3, pp. 22-23.

<sup>8</sup> D. L. McBride, "Metal Progress," 1941, June, vol. 29, No. 6, p. 717.

<sup>9</sup> Proceedings of the A.I.M.M.E., Open-Hearth Conference, 1941, p. 124, et seq.

<sup>10</sup> T. P. Colclough, *Journal of the Iron and Steel Institute*, 1936, No. 11, p. 547P.

<sup>11</sup> Proceedings of the A.I.M.M.E., Open-Hearth Conference, 1941, p. 147, et seq.

many plants have resorted to packing charging boxes by hand. Users of miscellaneous scrap have found that contamination with earthy matter brings the  $\text{SiO}_2$  content to about 1½% of the weight of dirty scrap. The problem of alloy contamination of scrap is becoming increasingly serious, and spark testing has been recommended as the most suitable method of sorting scrap of this type.

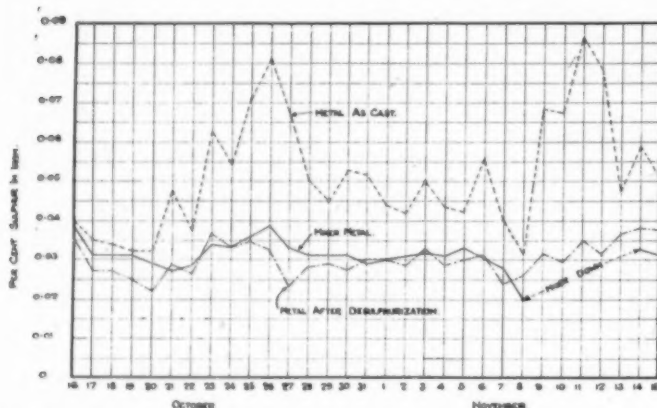


Fig. 3.—Comparison of sulphur in the iron; metal as cast, metal after desulphurisation, mixer metal.

Such ordinary methods of scrap preparation are essential if charging time is to be saved. Some works save time and fuel in the open-hearth furnaces by returning the cogging mill scrap without delay and recharging it while still hot. Other works make "synthetic" scrap. This may be done either in an open-hearth furnace or in a Bessemer converter. In the furnace process, light miscellaneous iron and steel scrap may be melted at a low temperature with a fairly high-carbon content and may then be desulphurised with soda ash in the ladle. The use of a converter is virtually the first step of a duplex process, although in some cases the blown metal is cast into moulds, and not poured directly into the open-hearth furnace, as in a true duplex process.

There is probably a future for thermal scrap preparation. Scrap bundles of sheets, turnings, etc., are easily fused on the surface, after which the entrapped air effectively insulates the interior from the flame. The melting of such material would be much facilitated were it thoroughly pre-heated before charging into the open-hearth furnace. Such heating could be satisfactorily done by blast-furnace gas or other low-grade fuel.

The type of scrap selected for a given charge usually bears a relation to the quality of steel required. The standard charge may be composed of heavy and light scrap in fairly fixed amounts, but variations will be made from time to time. For example, any scrap suspected of containing alloyed elements would be excluded from a heat destined for a deep drawing job; while low-sulphur stock would be selected for a charge of a particularly rigid slow-sulphur specification.

(3) *Charge and Feed Ore.*—The basic open-hearth operator usually considers that a low-silica content and a high-specific gravity are the two principal requisites of steel-making ore. Swedish magnetites were generally used before the war.

When ore containing a high proportion of fines is used, it is best to put the fines in the furnace with the charge and to reserve the lumps for feeding. Some plants screened their ore through 6-in. and on 3-in. mesh, and so obtained a size that was suitable for both charging and feeding. American operators have recently spoken favourably of sinter as a steel-making ore, claiming a saving of 10–12% in heat time compared with charges worked with their usual ore. In the author's experience, the only disadvantage of sinter is its high porosity, and if the composition of the mixture could be adjusted to produce a sinter of greater

bulk density than normally favoured for blast-furnace use, the product might well be very suitable for steelworks use.

(4) *Lime and Limestone.*—The suitability of a limestone for basic open-hearth use is largely determined by its silica content in bulk. A piece of the limestone itself may have a low-silica content, but the silica percentage in the truck may be high owing to the presence of flints in the lumps of stone or to contamination with clay. Most melting shops working the hot-metal process use limestone with the charge, and burnt lime for feeding. The  $\text{CO}$  evolved by the stone during the melting period is valuable both for the agitation it gives the bath and for its oxidising action. Further, to help regularity most plants specify a maximum size for limestone.

Some plants using the high-scrap, cold-metal process prefer to use only burnt lime with the charge. The lime is sandwiched between the scrap and the pig, so that the melting iron is forced to sink into the layer of lime. In the control of burnt lime quality, the sulphur as well as the silica content must be watched. A sulphur pick-up occurs during the burning of the stone, the amount of the pick-up depending largely upon the sulphur in the fuel.

*Scheduling of Operations.*—Attention having been drawn to the principal desirable qualities of the chief steel-making materials, it must be pointed out that granted acceptable quality the open-hearth operator's main requirement is *regularity*. Take the case of the silicon content of iron as an example, and suppose the open-hearth operator has asked for 0.90% Si. He will do better work if the supply he gets is steady at 1.20% than he will if one day it is 0.90% and the next 1.50%. True, he can make some allowance for the alteration, but, unfortunately, in a blast furnace the silicon is not the only condition that alters, and the open-hearth man cannot allow for them all.

The reason he asks for regularity in the supply of materials is that there are plenty of other things that he must allow for. No two furnaces work exactly alike, and, apart from small differences, it is usually possible to group the furnaces working in a shop as fast, medium or slow. A fast-working furnace needs more ore with a standard charge than a slow-working furnace; the latter by taking time does more oxidising by the furnace atmosphere. The slow furnace must have more time for the charging of a standard amount of scrap. Furnace speed, therefore, is the main variable to be allowed for with a standard charge.

Other necessary allowances concern the type of steel to be made, its desired composition and quality. Every shop making steels to a wide range of carbon contents must try to get melts with sufficient carbon to work the heat properly, neither so high as to require excessive oreing, nor so slow as to prevent an adequate boiling period being obtained. Accidents and irregularities naturally happen, and it is good economy to have a rolling programme elastic enough to permit open-hearth orders to be switched to soft or hard according to melting conditions. The economy arises from the saving of time in the melting shop and the avoidance of off-grade heats.

## Errata

In the article on "The Basic Open-Hearth Furnace To-day," published in our August issue the following corrections should be made:—The caption to Fig. 5 should read, "This design of furnace incorporates the type of conventional block that is being superseded." Fig. 6 should read, "The Venturi Furnace." Fig. 7 should read, "Design of block in the Maerz furnace."



# The Linings of Large Basic Open Hearth Tilting Furnaces

By A. Jackson

(Appleby-Frodingham Steel Co., Ltd.)

*The author first deals with the problem of linings from the viewpoint of lining stability when the furnace is tilted, particularly with regard to the lining on the charging side. These two types of operation and the resultant methods of fettling are briefly outlined. The causes of excessive hearth wear are enumerated, and the resultant effects on the brickwork of the hearth and linings described. Further, the materials now being used for the brickwork of the furnace body and for lining maintenance are discussed. Future prospects are briefly reviewed, and a brief summary of the brick consumption on two modern furnaces is given in an appendix.*

*This is an advance copy of a paper to the Iron and Steel Institute.*

**L**ARGE basic open-hearth tilting furnaces are designed primarily to work with large percentages of relatively impure molten iron. For economic reasons these furnaces are of large capacity, usually charging a minimum of 200 tons. On account of the high structural cost they utilise a deep bath, generally in excess of 33 in., with steep sides, which, when working, will probably be at an angle exceeding  $60^\circ$  to the horizontal. This angle is far greater than the normal angle of rest of the dolomite fettling as applied during working. For tapping and slagging the furnaces will tilt some  $35^\circ$  and  $15^\circ$ , respectively, giving a total movement of about  $50^\circ$  as a maximum (see Fig. 1).

From the viewpoint of front-lining stability the tapping angle ( $35^\circ$  maximum towards the pit) is important, and this angle can be minimised by the use of a tap-hole situated as near as possible to the furnace bottom. The fact that this necessitates a greater tilt in the opposite direction when closing the tap-hole has normally no appreciable effect on the stability of the back lining.

In the Appleby tilting furnaces the steel casing of both the front and back of the furnace is at about  $80^\circ$  to the horizontal. The back lining, which is of uniform thickness from sill level to roof, will only just pass the vertical even when the furnace tilts its maximum angle towards the charging side; thus, unless serious undermining has taken place, there is no danger of this brickwork becoming so unstable as to fall into the bath should the furnace ever be tilted to its maximum of  $15^\circ$ .

The problem of the front lining at tapping is far more difficult. In the first place this lining is tapered down from sill level to roof, thus reducing its angle from about  $80^\circ$  on the outer steel plate to about  $72^\circ$  inside the lining. A new lining, without undermining, or slag-level wear, therefore, passes the vertical when the furnace is tilted only half of its normal travel towards the tapping side, and this angle of, say,  $18^\circ$  is exceeded at practically every tap and, of course, at the time when the furnace is at maximum temperature and the under-cutting action of the slag at bath level is a maximum for that particular charge.

The normal instability of the front lining is thus demonstrated. Its tendency to fall is minimised by the use of relatively slight silica bricks in the upper part, bonded into the roof. In this case the face of the bricks will be so fused after a few charges that the roof and lining will form an almost monolithic structure. This can be contrasted with a chrome-magnesite lining, which is much heavier, does not frit and bond nearly so well, and may even be subjected to "growth" near the roof and under-cutting at sill level, thus materially increasing the tendency to become top-heavy. These factors are borne out in practice by the tendency of chrome-magnesite linings to fall out and collapse at tapping.

The first essential for lining stability is that the foundation should be solid and of adequate thickness at sill level. This must be attained by the use of hard-wearing brick-

work and good fettling throughout the furnace campaign. The necessity for good-quality dolomite for fettling is fundamental to the reduction of the quantity of magnesite used per ton of steel produced.

## Fettling of Tilting Furnaces

Tilting furnaces may be operated in two ways:—

- (a) Empty after each charge.
- (b) Leave all the refining slag and some steel in the furnace at tapping.

The former method generally uses higher percentages of scrap than the latter to obtain optimum results.

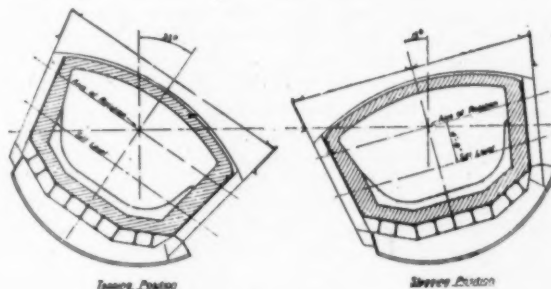


Fig. 1.—Outline section of Q furnace.

Fettling of furnaces using the former method will give a bank with an angle about equal to the angle of rest of dolomite. The base of the bank will extend some 4 ft. into the furnace hearth both front and back. This gives a serious reduction in capacity, and in consequence reduced output; furthermore, a furnace does not work so well with banks of this shape as when they are more nearly vertical. The rate of output is further reduced by emptying the furnace each time. The dolomite consumption is fairly high, as the whole of the hearth is subjected to slag action.

Due to the thick banks the degree of stability of the front lining should be fairly high and the magnesite usage low. The production will not be as high as it could be. Furnaces operating on this method should require very few magnesite bricks in the banks, as the dolomite cover is very thick in most places and stabilised dolomite bricks could be largely used.

In the second method, it is not possible to fettle from the bottom, as the bath will contain 12–20 in. of liquid after tapping. In any case, this is seldom necessary as the liquid remaining in the furnace at tapping protects the lower portion of the hearth.

To fettle, the slag is thickened by the addition of a portion of the charge and the dolomite rests on the almost solid slag. The bulk of it should burn on during subsequent operations. In this instance fettling is only applied round

about the normal slag line, which is, of course, the point at which maximum cutting takes place. The bath capacity is kept up and gives greater output, and this is further increased by leaving metal and slag in the furnace at tapping. The dolomite consumption is reasonably low, but greater attack of the magnesite brickwork is liable to take place, thus reducing the stability of the upper lining and increasing thereby the magnesite and chrome ore used in its maintenance.

In normal times the increased steel production and increased value of the basic slag do far more than compensate for any extra cost of magnesite materials.

In a tilting furnace working on this latter method the magnesite brickwork will be gradually worn away throughout the furnace life, due to its being periodically exposed to the action of slag and metal when the dolomite has been worn away. This periodic attack on the magnesite cannot easily be avoided, as it is caused by the following factors:—

(1) Variation in iron quality, which may give excessive cutting by steel or slag (e.g., increase in silicon content).

(2) Excessive foaming, which cuts the banks above the normal level; this effect is made worse by the increased flame attack just above the surface of the foam.

(3) Prolonged refining time (special steels or high-sulphur iron).

(4) Poor fettling—e.g., not fully burnt in before adding molten metal, or bad placing of the dolomite.

(5) Badly prepared dolomite—i.e., not fully shrunk.

(6) Various operational delays to the process.

Most of these factors occur in all furnaces, but in a tilting furnace, in which some slag and metal are left at tapping, the fettling is probably thinner than average owing to the limitations of the method used for fettling.

To summarise briefly, to obtain good output it is practically unavoidable that the brickwork of the hearth is quite often exposed to slag and metal action. If the bricks are not highly resistant then the lining is undermined deeply, and this cavity cannot possibly be filled tightly with dolomite; thus sinking and, finally, collapse will take place. The only satisfactory way to fill deep undercutting is by using a wet chrome-magnesite paste, "placed" with long-handled shovels, and finally covered with dry dolomite.

The collapse of an undermined lining is not generally very sudden, but takes place by the bottom courses sinking at the inner ends, giving ever-widening joints above, and finally a vertical layer will gradually but completely break away. This is followed by another layer after further undermining, and so on. The lining again can only be saved by pasting the ever-widening joints with a wet ground mix.

### Types of Bricks for Lining Basis

The type of brick necessary to form a basis for the lining must, when in contact with slag or metal, have a high resistance to reaction. It must also have a low shrinkage at high temperatures. These conditions were probably best fulfilled by Austrian magnesites, and to a somewhat less extent by bricks produced from the purer magnesites. The latter magnesites could probably be as good as Austrian, but in practice this is often not the case, possibly owing to the greater difficulties involved in the production of bricks from the purer material.

The alternative basic bricks, chrome-magnesite and stabilised dolomite are definitely less good and wear away relatively rapidly near the sill level. The mode of failure probably differs, in that dolomite bricks are mainly removed by slag attack, whilst chrome-magnesites are susceptible to the attack of molten mixer metal, which, of course, will be present in the early stages of the operation. The present position regarding the suitability of various basic bricks

below sill level is considered at Appleby-Frodingham to be as follows:—

**Magnesite.**—These bricks appear (from observations in use) to be slightly less resistant to attack than pre-war types. No equally good substitute for all-round use has been produced.

**Chrome-Magnesite.**—For furnaces using high percentages of molten iron these bricks do show some advantage over dolomite bricks where exposure to metal and slag is to be expected, though they are definitely less good than magnesite. For linings above slag level, the best types are better than straight magnesite.

**Stabilised Dolomite.**—Assuming that no possibility of powdering is involved, these bricks are satisfactory in all positions where they can be well covered with dolomite fettling.

If they become exposed they offer a good resistance to wear by molten steel and are therefore quite good for the furnace bottom if out of contact with slag.

In contact with slag, they wear rapidly when compared with the magnesite and chrome-magnesite bricks; similarly, they cannot be exposed to flame action above slag level owing to their high-spalling tendency and shrinkage.

### Linings up to Sill Level

**Bottom.**—Our experiments indicate that a 7½-in. thickness of magnesite (used as three 2½-in. courses) is satisfactory for the furnace bottom. If the frequency with which complete bottoms are renewed, and the loss involved in a break-out are considered, there is really no valid reason for reducing this thickness further at the moment. The remainder of the bottom, and some 12 in. of the banks, can also be put in with dolomite bricks quite safely.

**Front Bank.**—Trials on some fifteen furnaces indicate that dolomite bricks are unsuccessful. They invariably wear rapidly, and so cause undue maintenance on the lining by undermining. Three main factors contribute to this:—

(a) More difficulty in inspection and fettling.

(b) A small degree of undermining is very liable to cause failure in the front lining, owing to the considerable angle of tilt at tapping.

(c) In charging, the machine will dump portions of certain materials on the banks, and the metal is poured in on this side.

The only satisfactory brick for the front bank at present is magnesite.

**Back Bank.**—The base previously mentioned consists of some 12 in. of dolomite brick, then about 12 in. of magnesite are put on, followed by not more than 24 in. of dolomite brick. This brings the lining near slag level. Continuation above this point results in back-lining trouble, caused by under-cutting and shrinkage of the dolomite bricks. In the several instances where trials were made, using more of these bricks, the back lining gradually bowed out from the casing and eventually collapsed. Subsequent examination showed that the bowing outwards commenced in the dolomite portion of the furnace bank; thus the wash-line of the furnace at the back should also be of magnesite. Very careful fettling is essential to give moderate success with stabilised dolomite bricks.

**End Banks.**—About 12 in. of magnesite are used on the bottom, and then dolomite bricks are taken up to sill level. This is successful, because the end banks have little lining weight to support; also the slope is much less steep than at the front and back banks, and approximates more nearly to the angle of rest of the dolomite fettling. Good fettling is easy, and the maintenance of a good dolomite coating has no great effect on the furnace capacity. Even here, however, some shrinkage occurs, and the splays are liable to show sinking, with consequent widening of the brick joints. These must be fettled lightly with magnesite paste in the early part of the campaign.

### Linings above Sill Level

**Splays.**—The dolomite bricks are taken just above sill level and separated by two or more courses of magnesite bricks from the silica above, which is taken right to the roof.

**Back Lining.**—From about sill level chrome-magnesite bricks are used to the roof, with two courses of silica on top. Present chrome-magnesite bricks often show more bursting than pre-war types, but if the thickness of the base of the lining can be maintained, these linings are still quite successful.

**Front Lining.**—Magnesite or chrome-magnesite bricks are used to about 12–15 in. above sill level, the remainder to the roof being of silica. Chrome-magnesite pillars have been tried on several occasions, but do not offer any decided aggregate advantage owing to their liability to fall into the bath.

### Maintenance of Linings

Linings are patched when necessary with well-ground chrome-magnesite paste. Formerly this paste contained upwards of 70% of magnesite. Experiments have been made using as little as 20% of magnesite, but patching was not so successful; some saving in magnesite was obtained, but greater quantities of paste had to be used. Now a paste containing 40% of magnesite is considered to give reasonable satisfaction, but if equal difficulty were found in obtaining supplies of chrome ore as of magnesite, then a reversion towards a paste of higher magnesite content would result in aggregate savings.

Little paste is used on the back and end linings (splays) of the furnace, the bulk being used to maintain the front.

Some little saving has resulted from commencing the pasting of the linings from a higher level than was previously done, but as undermining is the main problem, the saving is not as great as might have been expected. High-chrome pastes are not as successful as high-magnesite types for slag-line patching; in consequence, the use of the 40% magnesite paste for this purpose is conducive to waste.

Trials without pasting have been made, but trouble quickly arose even with chrome-magnesite pillars in place of silica.

### Future Prospects

It is hoped in the near future to perfect a stabilised dolomite cement with which to repair front linings in place of chrome-magnesite. This material will, of course, necessitate a basic lining, and some method will be necessary to tie these bricks to the furnace structure to prevent

overbalancing. Water-cooled pipes of various shapes have been experimented with, and have shown some measure of success, but one or two nasty experiences resulting from undetected water leakages preclude this method from the possibility of real success.

Methods using metallic strips welded to the casing are being considered, but as the outer furnace plating forms a continuous structure, the relining would be slowed up, whilst rebuilding of a new lining with the furnace in commission would be impossible if welded strips were found to be essential for structural stability.

Further methods are being considered, but until substantial quantities of this cement have been used it is not possible to forecast how the difficulties will be overcome.

### Summary

(a) Magnesite and chrome-magnesite bricks are not of the same high quality as that attained about three years ago.

(b) Chrome-magnesite bricks are probably still superior to magnesite for the linings of open-hearth tilting furnaces above the slag line.

(c) Stabilised dolomite bricks can be used in part in the lower portions of the hearth to replace magnesite. They must be kept covered with fettling, or their life is poor.

(d) Magnesite bricks are still the only satisfactory bricks for use about the slag line.

(e) Stabilised dolomite cements may replace a reasonable portion of the chrome-magnesite cement used for lining maintenance, if present experiments in manufacture are successful.

(f) The dolomite used for ordinary fettling must be fully shrunk and in good mechanical condition (suitable grading, etc.) to give the maximum reduction in consumption of magnesite and chrome materials.

APPENDIX.—BRICK CONSUMPTION OF TWO RECENTLY BUILT 300-TON FURNACES.

Working weeks .....	178.6	119
Time working, % .....	90.8	93.3
Total production, tons .....	347,323	230,863
Tons per working week .....	1,945	1,948
Brick consumption:		
Silica bricks, lb. per ton .....	16.31	16.74
Firebrick, lb. per ton .....	1.54	1.16
Magnesite, lb. per ton .....	1.92	1.22
Chrome-magnesite, lb. per ton .....	1.13	1.55
Stable dolomite brick, lb. per ton .....	0.82	0.50
Total brick consumption, lb. per ton .....	21.72	21.17

The working weeks commence when the furnace is gassed and include all minor repairs.

The author wishes to thank the management of the Appleby-Frodingham Steel Co., Ltd., for their permission to publish this paper.

## Copper-Bearing Steels for Heavy Fabrication

*Copper-bearing steels with high copper contents—0.25 to 0.30%—have been found to develop surface cracks when heavily worked. The problems involved in the hot-working of these steels and the causes of surface cracking have been investigated and the results are summarised.*

**M**ANUFACTURERS of pressure vessels, tank cars, oil-refinery equipment, heavy metal containers, etc., make considerable use of copper-bearing steel, in order to resist corrosion and for reasons of structural strength. Where the fabrication is at all massive, there is the ever-present danger that such operations as forging, hot-rolling, hot-forming and welding will result in a denuding of the copper through preferential oxidation of the iron at the surface, with consequent surface cracking because of the low melting-point of the copper. This danger is aggravated by the relatively high residual copper present in some open-hearth steels, introduced therein from the scrap used in their manufacture. The problems involved in the hot-working of such steels and the causes of surface-cracking have been investigated recently by

F. Eberle,\* and some of the methods used for their improved fabrication discussed.

Copper and nickel are less readily oxidised than iron, and as a result, in a prolonged heating at rolling or forging temperatures in an oxidising atmosphere to steel, as in a soaking-pit or a billet-heating furnace, the steel scales, and in copper-bearing steels the scale consists of iron oxide, with a film of metallic copper or nickel or copper-nickel alloy left between the unoxidised steel surface and the layer of scale. Copper melts at 1,085° C., nickel at 1,450° C., and alloys of copper and nickel have intermediate melting-points, a 60–40 copper-nickel alloy melting at 1,205° C. At a heating temperature, therefore, of 1,100° C. for forging or rolling, a copper film is molten, a nickel film is not, and

\* *Metals and Alloys*, 1942, vol. 15, No. 4, pp. 588–594; No. 5, pp. 758–762.



a copper-nickel film may be liquid or solid, depending on its copper-nickel ratio. If the film is liquid it penetrates into the intercrystalline boundaries of the steel.

The effect of a copper film depends on its thickness—that is, upon the amount of copper in the steel and upon the amount of scaling that occurred during the formation, which latter in turn depends on the time, the temperature, and the atmosphere of heating. A molten film of infinitesimal thickness penetrates only a very shallow layer of steel, while a solid film does not penetrate. A thick, molten film may penetrate quite deeply to produce surface roughening, and in severe cases forging or rolling cracks, particularly edge cracks.

Surface-cracking troubles may be avoided by keeping the copper at a sufficiently low level; by adding enough nickel (if enough is not already present as residual nickel) to keep the film solid at the heating temperature; by lowering the heating temperature to such a point that the copper-nickel film, whatever the composition, remains solid; by heating in a non-scaling atmosphere; or by making the heating time so brief that despite the formation of a liquid film the film is of negligible thickness and effect. All these factors of amount and ratio of copper and nickel, of atmosphere, and of heating time and temperature may vary considerably. The composition as to copper and nickel varies from heat to heat of steel, depending on the nature of the scrap, the heating conditions vary with the mass of the billet, plate, etc., that is to be hot-worked, with the amount of work to be done on the piece, and with the heating practice of the plant.

For ordinary rolling conditions it is usually considered that no appreciably harmful effects can be noted until the copper content rises above 0.30%. Some steels alloyed with copper for resistance to atmospheric corrosion or to give a high yield strength are regularly produced with 0.4% of copper. The scrap used for such steels is selected so as to have the highest residual copper, so that the minimum copper additions is required, and scrap high in residual copper tends to be high in residual nickel also, so that a suitable copper-nickel ratio is usually present. Surface cracking may appear with as low as 0.2% copper in the absence of adequate nickel when high temperatures and long heating periods are involved, and to avoid such cracking the heating temperature must be lowered or the required nickel added.

In copper-bearing steels of 32 tons per sq. in. tensile strength used for boiler drum plates, the copper content is usually limited to 0.18%, and in the higher tensile material for drum heads to 0.12%, such limitations being necessary, due to the hot-working to which such parts are subjected. Recently, the question was considered of raising the copper content in the high-tensile plate material for drum plates and drum heads to 0.3 and 0.2% respectively, but before doing so it was decided to examine the practicability of higher copper content in such parts by suitable welding and forging tests on a steel containing 0.30% carbon, 0.61% manganese, 0.24% silicon, 0.012% phosphorus, 0.020% sulphur, 0.26% copper, and 0.02% nickel, and having a yield-point of 19.2 tons per sq. in., a breaking stress of 35.9 tons per sq. in., and an elongation of 26.25% on 2 in.

In the welding tests, two test welds were prepared, using two different types of electrodes, the test-plate being subsequently stress relieved at 650° C. No difficulties were met with in welding, and there was no indication of red-shortness or cracking in the weld metal and heat-affected zones. The weld properties were also satisfactory.

The forging tests were carried out under two sets of conditions: i.e., under very severe conditions, as might be encountered due to exceptional circumstances, and under normal fabricating conditions for drum heads. Tests under severe conditions included the determining of (a) the effect of prolonged soaking at maximum forging temperature upon the surface structure; (b) the hot-bending properties after

prolonged soaking at maximum annealing temperature; and (c) the forging properties after prolonged soaking at maximum forging temperature. Test-pieces heated to the maximum permissible forging temperature of 1,100° C. and maintained at this temperature for 4 hours showed intergranular penetration, while hot-bending tests carried out after 4 hours soaking at 1,100° C. indicated that, although the hot-bending properties were not critically affected by the higher copper content, shallow surface tears were produced which developed into more serious defects when the finishing temperature was allowed to drop below 925° C. Similar defects and cracks were also produced by forging below 925° C. after prolonged heating at 1,100° C.

Forging properties under normal conditions were studied by a forging test which reproduced the principal hot-working conditions of drum-head forging. For comparison with the 0.26% copper steel, the same test was made with a steel containing 0.31% carbon, 0.09% copper, and 0.005% nickel. The comparative forging tests, which were made after heating to 1,100° C. and soaking at that temperature for 1½ hours indicated that high copper content steel, 0.25 to 0.30% copper, could be successfully forged into drum heads, provided the temperature range of forging was maintained within prescribed limits, and also provided that the soaking time prior to forging could be kept below a certain maximum value. Such copper-bearing steel should not be heated to above 1,040° to 1,065° C., and should not be worked below 925° C. In actual fabrication, however, the steel is probably worked up to 1,100° C. and finished below 925° C., and under those conditions surface defects and a roughening of the hot deformed surface is to be expected, which may lead to the rejection of otherwise perfectly sound material.

In carrying out the various tests, it was found that copper content steel showed carbide coalescence in the grain boundaries. The reduced ductility associated with this condition is considered to explain the red-shortness which was observed in these copper-bearing steels above the lower transformation point. It was also thought to explain the extreme degree of fissuring which occurs in this steel when forging is continued into the temperature range of red-shortness, approximately 730° to 815° C.

### Discussion on the Determination of Equilibrium Diagrams by X-Ray Methods

A DISCUSSION, arranged for September 22 in the Lecture Theatre of the British Institution, and designed to bring together crystallographers and metallurgists for a frank interchange of views on the application of X-ray methods for investigating equilibrium diagrams, should be very valuable. This method has been used for this purpose mainly by workers who are crystallographers rather than metallurgists, consequently there is a tendency to overlook accepted metallurgical precautions in their experimental work. On the other hand, metallurgists have sometimes tended to consider X-rays as merely another tool for use in their work without appreciating that the information that X-rays give is fundamentally different from that given by all other methods. Much should be gained from this frank interchange of views which is arranged by the Institute of Physics.

The proceedings will open at 11 a.m. by an introductory statement by the President of the Institute, Sir Lawrence Bragg, F.Inst.P., F.R.S., and brief introductory papers will also be read. It is expected that the President will be supported by Dr. A. J. Bradley, F.R.S.; Dr. M. L. V. Gayler; Dr. W. Hume-Rothery, F.R.S.; and Prof. E. A. Owen, F.Inst.P. An afternoon session, from 2 to 4 p.m., will be devoted entirely to an informal discussion, and it is noteworthy that a strict time limit will be imposed on speakers.

# Railway Bearing Metals

## Their Control and Recovery

## Their Control and Recovery

By J. N. Bradley, A.R.S.M., B.Sc., and Hugh O'Neill, M.Met., D.Sc.

*In view of the present stringency regarding the use of tin and the desirability of adopting substitutes, this paper, prepared by the authors for presentation at the Annual Autumn Meeting of the Institute of Metals, will be of interest in connection with the utilisation of national supplies. Indentation and creep tests at 20° and 130° C., together with thermal cooling curves, have been obtained on tin-base and lead-base railway bearing metals. The L.M.S. impact and static shear tests, applicable to carriage and locomotive axle-box shells for routine inspection of white-metal adhesion, are described. Details are given of the new thermo-mechanical "Bradley process" for the complete separation of mixed borings of white metal and bronze. Aspects of the renovation of bearing metal are briefly considered, including limits of composition and impurities. This presentation is an abridgment of the original.*

**A** RAILWAY organisation may require to produce 1,500 tons of white metal per annum for use on bearings subjected to a variety of working conditions and pressures. Furthermore, its policy will probably be to di-metal all worn bearings, recover borings and sweepings, and renovate the alloys to standard specifications prior to re-use. As an example, the 1939 production cycle on the German State railways for high-tin white metal was as follows:—

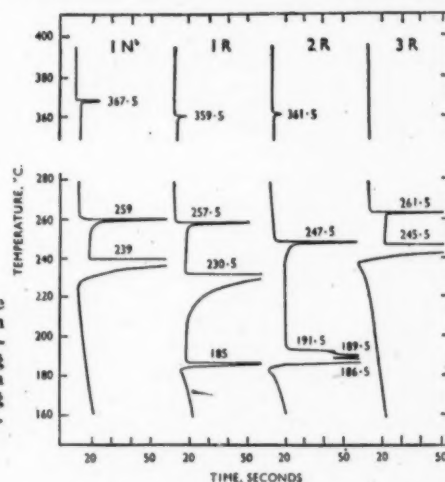
Old metal capable of re-use	81.4				
Metal from reclamation works	6.1	(	Boring, sweepings, dross....	6.3	
			Recovery loss .....	0	5
New metal to make up....	12.5	)	Foundry and works losses..	11.7	
			Losses by mixed borings ..	0	6
			Unmentioned .....	0	2

In all these operations questions of control, composition and economy are naturally to the forefront.

### Properties of Standard L.M.S. Bearing Metals

Up to recent years the four alloys specified in Table I have been in use on the L.M.S. railway. The thermal arrests of these metals recorded in Fig. 1 have been carefully determined by potentiometric methods during mechanical agitation of the contents of the cooling crucible.

Since there is a liability of extrusion effects at elevated temperatures and pressures, creep tests have been made of the four L.M.S. alloys. The test-piece chosen was a conical unmachined casting about 0.66 in. high, with an apex angle of 120°. This has the advantage that geometrical similarity is maintained when deformation is performed by loading against the apex, and the results are truly comparable one with another. Mallock has shown that the hardness values given by  $P_m = 4L/\pi d^2$  (where  $d$  is the diameter of the deformed flat), are independent of the applied testing load, and this makes such values superior to Brinell numbers for reference purposes. A weight-and-lever mechanism pressed the specimen against a bearing



**Fig. 1.—**  
**Inverse - rate**  
**curves on**  
**L.M.S. Stan-**  
**dard Bearing**  
**Metals at a**  
**mean cooling**  
**rate of 1.7° C.**  
**per minute.**

when flow had practically ceased, are reported in Table I. There is liable to be slight zero-error in recording absolute height, owing to imperfections of the conical point, and the tests at 130°C. were made on the specimens previously strained at 20°C. The test-pieces were cast from 400°C. into a steel mould preheated to 200°C.

### Comparison of Lead-Base and Medium Tin-Base Alloys

It was observed that the specimens 1R, 2R and 3R (copper 6%), which all have their strength undermined by the presence of lead-tin "eutectic," suffer most from creep under the influence of pressure. The lead-base alloy No. 3R is therefore superior to the 60% tin alloy No. 2R in this respect.

Kühnel<sup>4</sup> has shown that an alloy of this lead-base type offers better resistance to repeated impact than does one of the 60% tin type, though Greenwood's results suggest

TABLE I.—COMPOSITIONS AND MECHANICAL PROPERTIES.\*†

Alloy.		Specification Limits and Examples, %.				Brinell No. (10/500/15) at 25°C.	Mallock Hardness (kg./mm. <sup>2</sup> ), 21 days' load at †		Limit of Proportion- ality, lb./in. <sup>2</sup>	Young's Modulus, E, lb./in. <sup>2</sup> = 10 <sup>4</sup> ·		
L.M.S. No.	A.R.L.E. No.	Tin.	Copper.	Anti- mony.	Lead.		20° C.	130° C.		20° C.	60° C.	130° C.
6H	1N	84-86 85·0	4-6 5·00	9-12 9·73	0·2 max. 0·26	28·0	10·9	2·02	1500	7·7	7·0	4·6
6J	1R	80-85 81·2	4-6 4·3	8-10 9·8	5·0 max. 4·7	32·3	0·68	1·72	1061	7·5	6·7	3·4
6K	2R	58-60 58·9	2-6 2·4	9-10 9·3	Diff. 29·4	23·9	3·58	0·65	Low	4·8	4·3	1·0
—	3R	59·1 11-13 11·0	6-2 1·0 max. 0·4	9·8 12-14 13·0	24·9 Diff. 75·6	30 22·8	4·53	0·66	1132	4·3	4·2	2·9

\* Chosen from results on somewhat similar alloys obtained under special conditions by J. W. Cuthbertson, *J. Inst. Metals* 1939, 64, 209.

† See Fig. 1 for cooling curves of the chosen alloys.

\* For indentation tests on the micro-constituents, see H. O'Neill, *Metallurgia*, 1941, 23, 71.

that both have about equal resistance to pounding. Unfortunately, the former alloy is much more prone to segregation in thick bearings than is the latter. Archbutt and Deeley<sup>6</sup> remark that lead-tin-antimony alloys "are said to wear better than the tin-antimony-copper alloys . . . but they are less cool in running and, therefore, less suitable for high speeds." On the other hand, a lead-base alloy containing antimony 15% and tin 5% has been found capable of continuing in service under increased temperatures to a greater extent than many tin-base bearing metals,<sup>7</sup> and Fowler<sup>8</sup> reports satisfactory performance for railway work in the absence of hammering stresses and heavy loads. Apart from dangers of admixture in reclamation and metalling shops, it appears that lead-base alloys could be employed to a considerable extent.

### Metallurgic Procedure and Bonding Tests

Most of the bearing shells on the L.M.S. consist of a bronze containing tin, 7%; zinc, 4%; and lead, 3%, which is machined prior to its first white-metalling. Old bearings

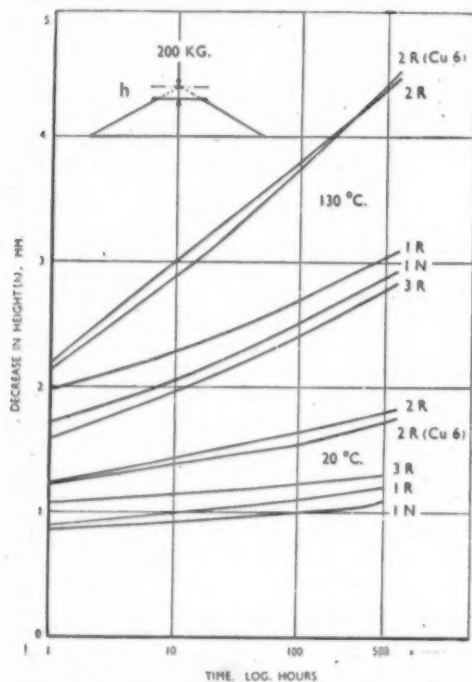


Fig. 2.—Creep tests on L.M.S. Standard Bearing Metals.

are de-metalled and degreased in trichlorethylene, but are not re-machined. Where the highest grade of white metal, No. 1N, is to be employed, the tinning might preferably be carried out with pure tin rather than solder, in order to avoid the presence of the easily fusible lead-tin eutectic at the interface. Otherwise the standard procedure is to preheat the bronze to 250°–275° C., flux the surface with solid sal-ammoniac or killed spirits, and then immerse the shell for some minutes in a pot containing molten 60% tin white metal (No. 2R) at about 375° C. The hot-tinned shell is next rapidly transferred to a preheated assembly of chills for metalling, and alloy is pouring in from the pots, using the following temperatures:—

	°C.
Casting temperatures: No. 1N alloy	375–400
No. 1R alloy	375–400
No. 2R alloy	375–400
No. 3R alloy	350–380
Chill temperatures: Rig-end chills	250–300
Other chills	100–150

Experience has shown that pyrometers and visual temperature indicators on white-metalling pots not only require a good deal of maintenance, but are liable to be

ignored by workmen when pressed for time. It was, therefore, recommended that the gas-heated melting pots should be thermostatically controlled, and this has been done with satisfactory results.

All engineers are anxious to obtain good bonding between the anti-friction metal and the bearing shell, for inferior adhesion is said to lead to excessive stressing of the white metal and a liability of hot running. If oil under pressure obtains access to the interface via a fatigue crack or chain of pores, heat conductivity from the white metal to the axle-box may be impaired, and detachment of the white metal will proceed steadily if the adhesion is poor. It is difficult during production to maintain proper inspection as regards adhesion, for a simple chiselling test is only very qualitative, and Mahoux<sup>9</sup> reports that sounding tests can be misleading. At the same time any specialised testing rig leads to specialised and unrepresentative treatment on the part of the workmen.

For inspection purposes an impact adhesion test was introduced on the L.M.S. in 1935, which uses carriage and wagon bearings as samples, and measures the energy required to detach the layer of white metal from prismatic test-pieces machined from the actual bearing. These specimens of  $\frac{3}{8}$  in.  $\times$   $\frac{1}{2}$  in. section are clamped in the vice of the Izod machine. A special striking shoe is arranged to rest on the Izod anvil and engages the thick white-metal layer at a distance of  $\frac{3}{8}$  in. above the junction with the

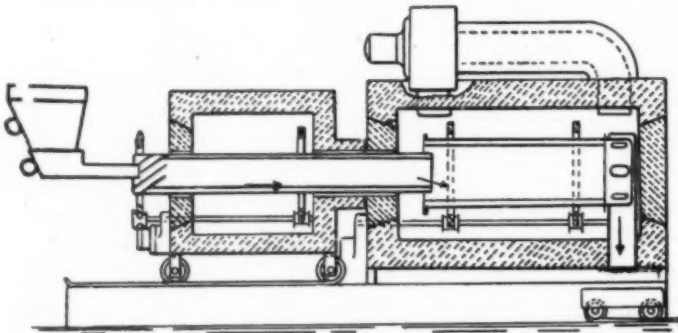


Fig. 3.—Furnace adapted for continuous operation.

bronze. Many railway bearing linings have hitherto been rather thick, and the test would require adaptation for thinner metal. With  $\frac{3}{8}$  in. deposits, a specimen 1 in.  $\times$   $\frac{1}{2}$  in. is machined with a horizontal step of  $\frac{1}{8}$  in. at the interface, and the tool of the striking shoe then rests on this step. Any machined ridges or grooves in the bronze are arranged to be parallel with the direction of movement of the Izod pendulum, and the ft.-lb. required to remove the layer of white metal is recorded as the impact adhesion value. Very good metalling practice gives a test-piece from which the white metal cannot be detached, the shoe actually shearing through the alloy rather than breaking it away from the bronze. Poor adhesion leads to values of only 3 or 4 ft.-lb., and as a result of the experience gained it is considered that this test should yield an average impact adhesion value of 23 ft.-lb., i.e., 30 ft.-lb./in.<sup>2</sup>. Values obtained for certain experiments are given in Table II. An auxiliary apparatus for white-metal adhesion experiments is illustrated in which bronze blocks,  $3\frac{1}{2}$  in.  $\times$   $2\frac{3}{4}$  in.  $\times$   $1\frac{1}{2}$  in., fit against a cast-iron chill having an internal runner so that the white metal may be bottom-cast against the vertical face of the block. Holes for taking thermocouples to measure the initial temperatures of both chill and blocks are provided, and the latter are afterwards sawn up into impact adhesion test-pieces of standard sizes. For locomotive axle-box shells, when the impact adhesion test would mean the destruction of a large bronze casting, another procedure has been devised which may similarly be applied to a proportion of the shop output for control inspection

4 R. Kühnel, "Werkstoffe für Gleitlager," Berlin, 1939.

5 H. Greenwood, *J. Inst. Metals*, 1934, 55, 77.

6 L. Archbutt and R. M. Deeley, "Lubrication and Lubricants," London, 1920.

7 A. H. Munday, C. C. Bissett and J. Cartland, *J. Inst. Metals*, 1922, 28, 141.

8 H. Fowler, *J. Inst. Metals*, 1924, 31, 3.

9 G. Mahoux, *Mecanique*, 1937, 21, 182.



TABLE II.—IMPACT ADHESION TESTS.

Exp.	Description.	Intermediate Tinning Alloy.	Impact Adhesion Value, ft.-lb.
A	Metal 2R (60% tin) on bronze— Tinning time 3 minutes.....	2R	26, 30 = 28
	" 7 " .....	"	34, 118 = 76
	" 15 " .....	"	33, 38 = 36
B	Proprietary tinning alloy tria .....	$\begin{Bmatrix} \text{Sn} & 55 \\ \text{Pb} & 42 \\ \text{Sb} & 3 \end{Bmatrix}$	104, 118 = 111
C	Bearing without serrations, cast vertically .....	2R	120 N.D.*
	Transverse serrations, cast vertically .....	"	120 "
D	Lead-base (3R) metal on bronze .....	"	37 "
		"	115 N.D.*
		"	78 "
		"	78 "

\* N.D. = white metal sheared but not detached.

purposes. This consists of shaping away some of the lining so as to leave projecting square, 1 in.  $\times$  1 in., test-pads of white metal. These are then sheared from the bronze by static loading in a compression testing machine with a special tool. In this test, alloy 1R tinned by alloy 2R has given the following results:—

TABLE III.

Test-Pad.	Shear Stress, Tons/in. <sup>2</sup> .	Remarks.
A	3.0	Sheared through white metal.
B	2.6	Sheared through white metal.
C	Nil	No adhesion though tinning appeared satisfactory.

Although present practice with bronze shells is to apply metal to a machined surface, it is nevertheless possible to obtain reasonable results on metal in the cast condition. A preliminary abrasion treatment by grinding, or sand- or shot-blasting, may be applied, but particles of grit may become embedded in the surface of the bronze and projected oil may be forced into deep surface irregularities. Experiments in this connection were made with test blocks previously mentioned, some of the surface area being machined and the rest being sand-blasted, and pickled for 10 minutes in cold acid (2 vols. conc. sulphuric acid, 1 vol. conc. nitric acid, 1 vol. water), following by washing in boiling water for 5 minutes and wire-brushing. Cold 33% hydrochloric acid could be used as an alternative, with subsequent neutralisation in hot 3% caustic-soda solution, followed by washing. Impact adhesion tests gave results shown in Table IV.

TABLE IV.—WHITE METAL IN ON BRONZE.

Condition of Bronze Surface.	Impact Test, Ft.-lb./sq. in.	
	Tested at 18° C.	Tested at 100° C.
Machined .....	25	11
Sand-blasted only .....	24	10
Sand-blasted and pickled .....	26	—

### Cast-iron Shells and Inferior Bonding

In these days of substitutes the value of grey cast iron as a shell for bearings should not be overlooked. Should the white metal run out, the iron backing has reasonably good bearing properties, since the flakes of graphite have been shown by electron diffraction to lead to a graphitic surface layer. The ferrite matrix of the iron will be harder than is desirable for some bearing purposes, and to this extent the use of hardened journals and lower speeds is recommended for continuous use against cast iron. In Germany, during the 1914 war, a soft, well-annealed hæmatite iron was used for machine bearings with success, and a Lanz pearlitic cast iron is also said to give good results as a substitute for bronze. Archbutt and Deeley\* also report that cast iron is suitable for bearing shells.

When such shells are to be metallised the bonding obtained is inferior to that produced on machined bronze, and according to Rolfe<sup>11</sup> is reduced by previously machining the iron. He recommends drilled peg-holes to ensure firm anchorage,\* and quotes Wohlert to the effect that an alloy

of two parts 50 : 50 solder and one part zinc should be used for tinning. An improved procedure is preliminary anodic etching, followed by copper-plating and tinning.

Most practice takes care to secure good bonding, but caution should be used in explaining away a defective railway bearing solely on the grounds of poor adhesion. For thick deposits of white metal the following evidence must be considered:—

(a) A zinc-base alloy successfully employed on the old Caledonian railway was applied to pocketed axle-boxes, big-end bushes, etc., without any tinning operation or bonding.

(b) The Swedish railways consider that bonding is unnecessary in carriage bearings. Unmachined bronze shells having two transverse, tapered, dovetailed grooves, together with a specialised keying section at each end, are found to be sufficient to hold the thick white-metal lining, and tinning is not performed.

(c) The carriages and wagons of the German railways use lead-base alkali-hardened bearing alloy, which does not bond with the shell, but is retained by two parallel, dovetailed keying grooves, together with an undercut section at each end.

Incidentally, the German railways have recently used a lead-bronze for large axle and connecting-rod bearings on locomotives; whilst for carriages a copper-lead alloy containing 25–30% lead (1.5% zinc and 0.2% iron tolerated) is used on galvanised steel-bearing shells which carry special ridges to prevent rotation of the lining.<sup>10</sup>

### Thin Linings and Centrifugal Casting

It should be emphasised that one desirable way of economising on railway bearing metal is to reduce the thickness of the deposit. A relatively thin film subjected to oil pressure will, according to R. W. Bailey,<sup>12</sup> have lateral stresses in the oil which are not very far from uniform, and of the order of magnitude of the oil pressure. In such a thin lining, as distinct from a thick one, the shear stress across the section would disappear and fatiguing action at the surface of the metal would be reduced. It is now generally agreed by metallurgists that a thin layer of white metal is superior to a thick one. Tests on white-metal bearings with thicknesses ranging from 0.1 mm. to 2 mm. by Hummel<sup>13</sup> show that the fatigue strength and bending strength are highest in the thin metal. For bearing diameters greater than 100 mm., he considers that the white-metal thickness should be 0.4 mm. minimum.

For the production of thin railway bearings, Beilfuss<sup>14</sup> recommends the use of a jig accommodating two semi-circular bronze carriage shells communicating with the liquid white metal and a cylinder of nitrogen. The latter blows the metal into the mould and provides a pressure-casting effect. Coupling-rod bearings with 1 mm. linings are produced in this way on the Reichsbahn, the final surface finish being a rolling which breaks up the cuboid structure.<sup>15</sup> Many British metallurgists would deprecate such surface rolling.

Centrifugal casting is a satisfactory way of producing thin linings. Driving motor bearings on the Swedish railways have a lining 2 mm. to 3 mm. thick, obtained by rotating the pre-heated tinned bronze shell at 900 r.p.m. The liquid white metal is introduced internally from a moving feed-pipe and the outside of the shell is afterwards cooled with compressed air. If the linings are thicker than about 5 mm., there is a segregation of the constituents and the copper content is high on the outside. Garbers<sup>1</sup> also records that if a speed of 1,200 r.p.m. is used with a lining 12 mm. thick, the white metal is severely segregated. At 600 r.p.m., and with a 6-mm. lining, segregation is prevented. Haas<sup>10</sup> has outlined the centrifugal lining of cylindrical bearings with a white-metal layer only 1.5 mm. thick, in which the use of tinning was dispensed with.

<sup>10</sup> P. Haas, *Metallwirtschaft*, 1940, 19, 1115.

<sup>11</sup> R. T. Rolfe, *Trans. Manchester Assoc. Eng.*, 1929–30, 13.

<sup>12</sup> R. W. Bailey, *J. Inst. Metals*, 1934, 55, 99.

<sup>13</sup> O. Hummel, *Metallwirtschaft*, 1939, 18, 863.

<sup>14</sup> E. Beilfuss, *Z.V.A.J.*, 1936, 80, 1478.

\*In many cases in practice dovetail holes, and sometimes slots, are cast in shells to anchor the white metal.—*Editor.*

Experiments on centrifugal casting for side-rod bushes have been carried out at Crewe Locomotive Works. It was found that segregation occurred in the white metal when its thickness exceeded  $\frac{1}{8}$  in.

### Bearing Failures

A long account could be given of bearing failures, but it is seldom possible to state with certainty why a standard railway bearing has run hot, since the actual failure destroys most of the evidence. Imperfect lubrication is probably the chief cause. Carriage bearings frequently begin heating and melting at the radiused ends. In a hot bearing the more fusible portions of the alloy matrix become extruded from the mass and deposited on the trailing side of the journal, leaving behind cuboid constituent.

The surface of a bearing may develop shallow "groove markings" and fatigue cracks, and the latter eventually form the well-known "crazy-paving" network. They appear to start from the surface, and, if there is segregation, choose the zones of fewest cuboids, travel towards the shell, and generally change direction.

The machined surface of a bearing may show cavities or pores due to casting conditions. According to Shaw,<sup>17</sup> slight surface defects cause oil whirls which lead in a cumulative way to further damage. This effect does not appear to develop much trouble on rolling stock bearings, and the Swedish railways, for instance, find pores to be of no disadvantage. Porous bearing metals intended to retain oil are also well known. On the other hand, cavities in the vicinity of the shell junction, especially if adjacent to shell ridges, are liable to lead to cracking of the white metal. The crests of retaining ridges are danger-points, and may be the source of fatiguing cracks in automobile bearings. If ridges are used ample radius should be allowed both to facilitate tinning and metallizing, and to reduce stress concentrations.

Railways have to contend with dust and grit, and some years ago an experiment was carried out on the Great Western in which fine emery was supplied over a long distance to a carriage axle-box. This caused wear but not overheating, because the lubrication was good. Laboratory experiments confirm<sup>18</sup> that emery in the oil causes greater wear of the bearing. Case<sup>19</sup> considers that contamination by dust and grit was one of the causes of excessive bearing trouble in India, and during the dust storms in the United States in 1935 hot boxes trebled in number.<sup>20</sup>

### Reclamation of Scrap—the Bradley Process

Metal melted out from old bearings, together with melting dross, clean borings, and mixed borings of bronze and white metal from the machine shops, are concentrated at Derby Carriage and Wagon Works for renovation. Accidental admixture with some lead and zinc is liable to occur during this collection of metal, and doubt has sometimes been expressed as to whether renovated bearing alloy is as good as virgin metal of the same composition. The question of "modification" effects during melting must be borne in mind, but our experience has not brought to light definite defects due to renovation, and tests by Graebing<sup>20</sup> led him to conclude that the running properties of white metal did not deteriorate by repeated reclamation.

Mixed borings and various mixed residues require special treatments, and one way of dealing with the former is to liquate away the white metal on inclined hearths at a suitable temperature. A less-efficient way is to use a melting pot and skim off the "recovered borings" of bronze from the surface layer. With static liquation these processes leave behind a sinter of bronze and white metal, but by centrifugal liquation the bronze residue is much less contaminated with white metal than in the simpler

process. In an endeavour to obtain improved methods for dealing with mixed borings and residues, research was commenced in 1937 which ultimately led to the development of the Bradley process. Preliminary experiments conducted in a small drum, which was rotated in a thermostatically controlled oil-bath, soon showed that it was possible to powder the white metals without affecting the bronze. These results were so encouraging that it was decided to build a semi-large-scale plant which might later be adapted to form a continuously operated separation plant.

A special rotating drum furnace was designed and made for this work by Messrs. Birmingham Electric Furnaces, Ltd., and employed forced-air circulation and automatic temperature control. A steel drum, 1 ft. 3 in. in diam.  $\times$  3 ft. 6 in. long, rotates inside the furnace proper; this was later equipped with two fins 3 in. deep, which are diametrically opposed and extend along its whole length. The furnace is electrically heated, and its temperature is controlled to within  $\pm 2.5^\circ\text{C}$ . of the setting. A drum speed of 20 r.p.m. was found to be satisfactory, and experiments were conducted on charges up to 40 lb. in weight. These were sealed in the drum, and after heating to the set temperature were agitated for a period of about 10 mins. and then withdrawn without further cooling. The internal fins served to lift and drop the charge on to the interior surface of the heated drum, and by this means the white metal was reduced to a fine powder and easily removed from the bronze by sieving. The process\* is now coming into operation in Derby works, and the conditions necessary for batch and continuous operation are of interest.

*Separation Conditions for the Bradley Process in Batch Operation.*—White metals may be powdered throughout the solidus-liquidus range, but at the liquidus temperature itself no powdering takes place. Whilst a separation is possible by agitating anywhere in this range, the best results are obtained by working at an optimum temperature for each alloy and within a zone of  $5^\circ\text{C}$ . Thus, for alloy 2R, powdering commences at about  $185^\circ\text{C}$ ., but the best results are obtained at  $200^\circ\text{C}$ . At this temperature the powder produced will pass a 40-mesh I.M.M. sieve, enabling any charge of mixed borings coarser than this to be treated. Operating at a lower temperature produces a small proportion of coarse white-metal powder, while at a higher temperature some agglomeration appears to take place, resulting in the formation of some small balls varying in diameter from 0.02 in. to 0.04 in. Similar results have been observed with all white metals treated, and a narrow range for the operating temperature is considered best, that for alloy 1R being at  $220^\circ\text{C}$ .

*Continuous Operation of the Process.*—To secure increased output the above plant was converted to continuous operation. For this purpose the furnace was fitted with a feed and preheated as shown in Fig. 3. The feed consists of a hopper and chute activated by a Sinex vibrator. Material discharges into a preheating furnace consisting of a gas-heated thermostatically controlled rotating drum, 5 ft. long and 9 in. diameter. This is rotated at 20 r.p.m. by its own motor, and contains a charging helix for the first 6 in., followed by two diametrically opposed fins 2 in. deep, extending along the remaining length. The drum communicates directly with that in the original furnace, and the charge passes from one furnace to the other. Discharge of the treated material is effected by an extension cover with peripheral holes attached to the Birlec drum. This extension is enclosed by a metal chute which permits removal through the bottom of the furnace on to a container or a vibrating sieve. An agitation period of about 10 mins. is required for disintegration of the white metal, and to permit the contents to remain in the furnace for this period the whole plant has an inclination of about 1 in 100. It was soon found that the forced-air circulation system was unnecessary under these conditions, and it has been disconnected.

15 K. Martin, *Organ Fortschritte, Eisenbahntechnik*, 1935, 90, 23.

16 — Wagner, *Gleiserei*, 1936, 23, 619.

17 H. Shaw, *Assoc. Metal Sprayers [Publ.]*, 1937.

18 B. Kehl and E. Siebel, *Arch. Eisenhüttenwesen*, 1936, 9, 563.

19 H. C. Case, *J. Inst. Loco. Eng.*, 1939, 29, 708.

20 A. Graebing, *Braunkohle*, 1936, 35, 613.

\*British Patent No. 540536.



The continuous process is now giving very satisfactory results and the output is about 200-300 lb./hr. For mixtures containing alloy 2R, the preheater control is so arranged that the borings on passing to the second (separator) drum are heated to a temperature of 200°-220° C. The temperature in the separator is maintained at 165° C.—i.e., below the solidus of the alloy. Some powdering takes place in the preheater, and the remainder takes place on a temperature gradient in the separator. As the exit temperature of the white-metal powder is below the solidus, there is little or no tendency for the white-metal powder to agglomerate, and the addition of contaminants has not been found necessary when dealing with the usual run of shop borings containing up to 60% white metal. Mixed borings containing alloy No. 3R have not been put through this plant.

TABLE V.—PRODUCTS OF BRADLEY PROCESS.

	Bearing Metal (2R).			Bronze.	
	Specifica- tion.	Ex Clean Mixed Borings.	Ex Ligated Residues.	Ex Clean Mixed Borings.	Ex Ligated Residues.
Tin .....	58-60	60.0	60.2	8.1	12.4
Antimony .....	9-10	9.7	8.8	0.3	0.9
Copper .....	2-6	5.3	6.7	84.9	78.2
Lead .....	Diff.	25.0	24.3	3.5	4.4
Zinc .....	—	—	—	2.6	3.3
Iron .....	—	—	—	0.2	0.8
Undetermined .....	—	—	—	0.4	0.8

**Nature of Charges for the Bradley Process.**—The dividing sieve may conveniently be of 30- or 40-mesh I.M.M. size, and charges of mixed borings coarser than this are suitable for treatment. Any finer bronze particles will be carried through with the white-metal powder unless previously removed.

Charges of high white-metal content should be considered for liquation treatment, followed by Bradley treatment of the sintered and contaminated bronze. This bronze liquation product is skimmed from the pots and passed down a vibrating metal chute, so arranged that at the bottom the white metal is solid. The material is then of suitable size for passing into the continuous feeder. Such a scheme works quite well, but both the bronze and white-metal powder products require more renovation to restore them to specification analyses. Due to the limited output of the plant, it has been decided to use this dual method for charges high in white metal.

By batch operation it is quite feasible to obtain a fairly clean separation of any two fusible alloys with the required freezing range, provided that in the one with the lower solidus the optimum separation temperature does not exceed the solidus of the other. Actually, more latitude may be allowed in special cases where the solidus is represented by only a small proportion of a low-melting point eutectic. Alloy 1R fulfils the above condition, and when treating mixed borings containing bronze and both 2R and 1R bearing metals, the 2R alloy may be removed first, if desired, by operating at a temperature of 200° C., and the 1R alloy next separated from the bronze by a subsequent treatment at 220° C.

**Treatment of Separated Products.**—The operating temperature is apparently too low to cause any tinning of the bronze borings, and after the removal of the white-metal powder by sieving they may be melted and ingoted. Some slight adulteration is inevitable, and this is shown by a rise in the antimony and tin contents of the recovered bronze. The increase in the antimony content seldom exceeds 0.1%. Recovered borings from the liquation process are tinned, and hence show a more marked difference in composition. Analyses of bronzes obtained from treatment of alloy 2R mixed borings, and also from their liquated residues, are given in Table V.

The reconversion of the whole of the white-metal powder to ingot form is a matter of some difficulty when other than easily fusible contaminants are present. Methods based on the agitation of the powder in a sealed drum heated above the liquidus do not give complete reconversion, but the

white metal recovered by this means is low in copper. By the indirect extrusion of clean white-metal powder at 400° C., about 90% of the white metal may be directly obtained in ingot form. The remainder is obtained as a compact reject plug containing all the non-metallic impurities and the oil residues. Such remainders would require a final smelting treatment. There is much to recommend the extrusion method, as the temperatures and pressures required are low, but its adoption has had to be postponed for the duration of the war.

The powder, when mixed with 4% flux, can be directly melted to give bearing metal, and the operation may be carried out in a melting pot or small reverberatory-type furnace. The most economical use of the flux is obtained by stirring the white-metal powder into a bath of flux held in a melting pot. Successive small amounts can be added in this way until the flux cover becomes too pasty for further additions. During these operations copious oil fumes are given off, and even when the whole charge is molten, flames from oil residues are evolved. It is not practicable to wait until these have ceased, and hence the "slag" is rather vesicular. By this means 97-98% of the white metal may be directly obtained in ingot form. The remainder is present as shots of metal in the "slag" and may, if desired, be recovered by other means.

In Table V analyses of No. 2R bearing metal, separated from shop consignments of clean mixed borings and liquated residues, are given. In general, the increased copper content is the only appreciable change. It has been shown that it is practicable to effect a clean separation of each constituent and to reconvert the whole of the bronze, and at least 97-98% of the white-metal powder to ingot form.

Charges in a fine state of division, and also low in white metal have always been very difficult to treat by any process dependent on liquation, and for such material the method described is very well suited. The products obtained can be judged from the analyses quoted, and whilst the components cannot be recovered quite unaltered in composition, the total change is small, except in the case of liquated residues, and in both cases is within the limits required for economic renovation.

#### Limits of Composition and Impurities

The concluding section is devoted to a consideration of the economical limits of composition which will give good service from recovered and renovated bearing metal. This becomes doubly important under war conditions, and the authors offer some notes; thus, during the reclamation of alloy 2R there is a tendency for copper to increase, and in recent years their limit for this element has been raised from 3% maximum to 6% maximum. In the lead-base alloys copper is generally limited to about 0.5% maximum. Experiments on alloy 1R show that zinc can produce a "modification" of the microstructure, but the effect diminishes on remelting. The greatest influence was observed with 0.025% zinc. An L.M.S. service experiment with carriage bearings of alloy 2R containing an addition of 0.15% zinc, has shown that this amount does not impair normal running properties. In lead-base alloys, it appears that zinc contamination is neither desirable nor fatal. As an intentional addition of about 1% to high-tin bearing metals (1N), cadmium is giving good results in L.M.S. Road Motor Department engines. In lead-base alloys, a small addition appears to modify the eutectic matrix. There is but little danger of contamination of white metal with aluminium during renovation, owing to the difficulty of making this metal dissolve in the bearing alloys. For heavy duty, the higher-tin white metals have their properties undermined if the lead content exceeds about 0.25%. No occasion has arisen to determine a limit for arsenic. In high-tin alloys it hardens the cuboids; in lead-base alloys there is an indication that it confers valuable properties. Iron is limited to 0.10% in the high-tin bearing metals, but for lead-base alloys there is a suggestion that with 0.2% segregation is controlled.



## Memorandum on Post-War Education Training of Physicists

**T**HE Board of the Institute of Physics has ordered the circulation of a memorandum, prepared by Dr. H. Lowery, Principal of the South-West Essex Technical College, at the request of the Planning Committee of this Institute, with the object of providing open discussion on the vital problems of the training of physicists and of education in physics for those not specialising in the subject; the opinions expressed do not necessarily represent the views of the Board or the Planning Committee, but they do present an excellent basis for discussion from which subsequent recommendations will be made to the Board.

In this memorandum Dr. Lowery states: "Up to the present time it has been customary to use the term 'training of physicists' as referring only to the training of industrial physicists, and this, in turn, has applied mainly to the training of research physicists for industrial laboratories, finally reducing itself to preparation for an honours university degree, together with some post-graduate training in research methods.

In view of the widespread applications of physics in the modern world (e.g., in radio, aeronautics, refrigeration, rubber technology, geology, photography, plastics, architecture, etc.), and the need for supplying not only many routine workers for industry but an enlightened populace as well, scientifically minded enough to facilitate the spread of the latest discoveries, it is necessary to broaden somewhat the range of workers who shall be denominated "physicists." In this connection I would go to the extent of saying that certain chemists and engineers have had their energies diverted so far into the study of physical problems that they have virtually become physicists.

"It thus becomes necessary to revise the idea that the training of the physicist shall necessarily be the pursuance of an honours course in the university, followed by research, and to consider the possibility of new courses specially designed for producing physicists of the right type for industrial and commercial requirements.

"I feel also that, in spite of the fact that the majority of young people in schools and colleges who study some physics will never proceed beyond comparatively elementary stages, nevertheless, their training should be a matter for the concern of the Planning Committee of the Institute of Physics, and, to complete the circle, the education of the schoolmaster who will ultimately train young minds in physics studies should also receive our careful attention. It is important, however, that we should remember that although all school, college and university courses may have a vocational bias, nevertheless emphasis must always be upon education rather than upon vocation, and we must constantly fight against any tendency to narrow our school and academic courses to such a degree that they merely become highly specialised trade schools. At the informal discussion on the Training of Industrial Physicists,\* arranged by the Institute of Physics on February 11, 1936, there was no doubt in the minds of the representatives of industry as to the benefit to industry of the product from schools and universities provided that care was taken to supply a training in basic principles, together with the cultivation of the enquiring habit of mind."

He then proceeds to discuss industry's demand for physicists, whether the present university course fulfils all requirements, the content of university courses, pre-university courses, the position of technical colleges in the training of physicists, part-time and special courses, and some attention is given to modifications in the instruction of mathematics for physicists. This is a very thought-provoking memorandum, and should lead to considerable discussion, which is provisionally arranged to take place in London, on October 12.

\* J. A. Crowther, The Training of Industrial Physicists, *J. Sci. Instr.*, Vol. 13, p. 141 (May, 1936).

## Raw Materials for Chemical Industry

**O**NE of the many useful pre-war activities of the London and South-Eastern Counties Section of the Institute of Chemistry has been organised visits to works were operations of interest to members are in progress. An interesting wartime innovation was, however, made on August 26 last when a party of 50 members visited the Galleries of the Imperial Institute, at South Kensington, to inspect exhibits of Empire raw materials. The exhibits, in addition to showing the raw products and the conditions under which they are produced, in many cases also contain "story" exhibits which trace the course of many products from raw material to manufactured article.

The party was divided into three groups, each under the guidance of technical officers of the Imperial Institute, experienced in mineral, plant and animal products, and many interesting discussions occurred during the tour.

Sir Harry Lindsay, K.C.I.E., C.B.E., Director of the Imperial Institute, in welcoming the party, reminded them that what they had seen in the Galleries represented only one of the many activities of the Imperial Institute, and he referred to the work of the chemical and mineralogical laboratories where analyses and small-scale technical trials were carried out on new or little-known raw materials of Empire origin. He also drew attention to the work of the two intelligence sections, the publications, and the technical library, all of which were at the service of those interested in raw materials.

The Director stressed the importance of chemists becoming familiar not only with alternative Empire sources of supply of their raw materials, but also of the by-products therefrom and possible substitutes, and drew attention to cases where the waste product of one decade had become of primary importance in the next. In this latter connection he instanced the case of ilmenite, from Travancore, which for years was a waste product in the recovery of monazite from beach sands, but later, owing to the increasing use of titanium white paint, became the primary mineral yielded by the desposits which had been exported up to 250,000 tons per annum. In addition, other important minerals, such as rutile, zircon and sillimanite, were now also obtained as by-products.

Sir Harry also referred to the recent American work which seems to have demonstrated that an admirable plastic moulding powder can be produced from bagasse, the fibrous residue of the sugar-cane left after the sugar has been extracted, and mentioned that it had even been suggested in the States that in time sugar itself may become simply a by-product of a new plastics industry. The manufacture of the new plastic, cafelite, in Brazil from the coffee bean is another example of how the work of the chemist is altering the outlook on some of the major crop products of the world.

When the tour of sections of the Galleries had been made the party adjourned for tea, after which they went to the Institute's cinema, where a selection of Empire films was shown. These depicted scenes of life in India; the mining of manganese at Postmasburg, South Africa, its preparation and transport to Durban, and the production of ferro-alloys at Newcastle, Natal; ravages of a number of insect pests on fruit, and some methods adopted to combat them by means of sprays made up with petroleum emulsions, and a film depicting the cultivation and preparation for the market of cocoa, bananas, coconuts and other products in Trinidad.

The meeting was pronounced a great success, and Dr. J. R. Nicholls, F.I.C., in proposing a vote of thanks to the Director and his staff, suggested that the London and South-Eastern Section might well make such a visit an annual affair. As the Director had already indicated, however, visits from individual members would also be welcomed.

# The Chemical and Physico-Chemical Analysis of Iron and Steel

## Twelve Years' Advancement

By E. C. Pigott

### Part II. (Contd.)—Papers Describing the Determination of Single Constituents

#### Manganese

Much of the recent research applied to the determination of manganese in iron and steel has been directed to the persulphate method, the bismuthate process evidently being ranked as of secondary importance, presumably on account of the number of interfering elements. Even in the persulphate process, large amounts of chromium are undesirable and in a method evolved by F. W. Smith in 1937 all but a small amount is volatilized as  $\text{CrO}_2\text{Cl}_2$  from fuming perchloric acid solution by means of sodium chloride. The excess of chloride is readily expelled and the persulphate procedure may then be applied. Perchloric acid is an excellent solvent for chromium steels. In an investigation of the zinc oxide method, the present writer found that when applied to cast irons a double precipitation may be necessary, adsorption in certain cases being pronounced. Many different processes are discussed, and several contributors describe spectrographic technique. Manganese is very conveniently estimated by means of the photo-electric absorptiometer and Murray and Ashley have devised a dependable procedure; such technique is particularly advantageous when alloying elements are present.

#### REVIEW OF METHODS.

Scott. *Chemist Analyst*, 1938, **27**, 52-7.

#### OXIDATION BY PERSULPHATE.

Bagshaw. *J. Soc. Chem. Ind.*, 1939, **58**, 106.

Chukavin. *Zavod. Lab.*, 1936, **5**, 1246.  
(Effect of NaCl.)

Forsyth and Barfoot. *Ind. Eng. Chem. Anal. ed.*, 1939, **11**, 625.  
(3 drops of 0.01 M  $\text{OsO}_4$  extends arsenite reduction to  $\text{MnO}_2$ .)

Kjerrmann and Balekstrom. *Jernkonterets Ann.*, 1933, **117**, 178-91.

Kujel. *Zavod. Lab.*, 1936, **5**, 1245.

Lomfardo. *Met. ital.*, 1933, **25**, 415-27.

Malaprade. *Bull. Soc. Chim.*, 1932, **51**, 241.

Russell and Johnston. *Chem. Age*, 1936, **35**, 100.

Sandell. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 256.

Spillane. *Chemist Analyst*, 1931, **20**, No. 6, 11.

Zuttrius. *Z. anal. Chem.*, 1939, **115**, 400.

#### PERCHLORIC ACID PROCEDURES.

Johnson. *Iron Age*, 1938, **142**, No. 26, 16, 22.  
(In Cr-steels.)

Mikhina. *Zavod. Lab.*, 1939, **8**, 162.  
(In Cr-steels.)

Raab. *Angew. Chem.*, 1937, **50**, 327.

Smith. *Ind. Eng. Chem. Anal. ed.*, 1938, **10**, 360.  
(Removal of chromium as  $\text{CrO}_3\text{Cl}_2$ .)

Steinberg and Smith. *Ind. Eng. Chem. Anal. ed.*, 1941.  
(Oxidation of graphite by  $\text{HClO}_4 + \text{K}_2\text{Cr}_2\text{O}_7$ .)

#### POTENTIOMETRIC.

Dickens. *Mitt. W. Inst., Eisenfor.*, 1938, **20**, 35.

Dickens and Maassen. *Arch. Eisenhüttenw.*, 1936, **9**, 437-198.

Dickens & Maassen. *Mitt. W. Inst., Eisenfor.*, 1935, **17**, 191-202.

Genis, et al. *Zavod. Lab.*, 1940, **9**, 1082.

Hiltner and Marwan. *Z. anal. Chem.*, 1933, **91**, 401-11.

Khitarov. *Trav. inst. metrol. std.*, U.S.S.R., 1934, No. 621.

Khlopin. *Z. anal. Chem.*, 1935, **102**, 263-70.  
(In W steel.)

Miloslavski. *Zavod. Lab.*, 1935, **4**, 31-9.

Zanko. *Domez*, 1933, No. 8, 27.

#### ZINC OXIDE SEPARATION.

Pigott. *Analyst*, 1937, **62**, 860.

(With most cast irons, a double precipitation is advisable.)

#### MICROCHEMICAL. (PERSULPHATE METHOD).

Karenman. *Mikrochemie*, 1934, **15**, 289-94.

Leroy. *Bull. Soc. Chim.*, 1936, (5), **3**, 1125.

#### COLORIMETRIC.

Milvaskii. *Zavod. Lab.*, 1936, **5**, 12.

#### PHOTOMETRIC.

Dietrich. *Metallwirtschaft*, 1939, **18**, 811.

(Oxidation with  $\text{AgNO}_3 + (\text{NH}_4)_2\text{S}_2\text{O}_8$ .)

Hirano. (i) *J. Soc. Chem. Ind., Japan*, 1934, **37**, 147; (ii) *J. Soc. Chem. Ind., Japan*, 1937, **40**, 412.

(i) Titration method; (ii) In Co-Cr steel; titration method.

Mehlig. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 27.

(Available methods reviewed; precipitation of  $\text{MnO}_2$  by  $(\text{NH}_4)_2\text{S}_2\text{O}_8$  preferred since Ni, Cr, Co, and Zr and moderate amounts of W, Mo, and P do not interfere. Finally, oxidation with  $\text{NaBiO}_3$ .)

Muller. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 361.

(Straight lines based on Beer's Law preferred to curves obtained from series of standard solutions.)

Murray and Ashley. *Ind. Chem. Anal. ed.*, 1938, **10**, 1-5.

(Oxidation of  $\text{H}_2\text{SO}_4 - \text{H}_3\text{PO}_4$  solution with  $\text{KIO}_4$ .)

Sokotova. *Aviapromyslenost*, 1939, No. 3, 52.

(Oxidation with  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ .)

Pinsl. *Arch. Eisenhüttenw.*, 1936-7, **10**, 139.

(Oxidation with  $(\text{NH}_4)_2\text{S}_2\text{O}_8$ ; addition of NaF.)

Thanheiser and Heyes. *Arch. Eisenhüttenw.*, 1938, **11**, 31-40.

#### MISCELLANEOUS METHODS.

Bastien and Guillemon. *Bull. assoc. tech. fenderie*, 1937, **11**, 442-53; 1938, **12**, 16-23.

Dubinski. *Zavod. Lab.*, 1937, **6**, 624.

(Lange and Kirtz method.)

Gerke. *Zavod. Lab.*, 1935, **4**, 283.

Karsten. *Pharm. Weekblad*, 1935, **12**, 1327-39.

Krivenko. *Zavod. Lab.*, 1938, **7**, 217.

Lange and Kurtz. *Z. anal. Chem.*, 1931, **86**, 288-303.

Silverman. *Bull. Inst. Phys.-chem. Res. Tokyo*, **12**, 927.

Spillane. *Chemist Analyst*, 1931, **20**, No. 6, 10.

Stefanovskii. *J. Applied Chem., U.S.S.R.*, 1934, **7**, 1288.

Sullivan. *Metals and Alloys*, 1935, **6**, 134.

#### SPECTROGRAPHIC.

Bardocz. *Magyar Mernok Epit. Kozlonye*, 1938, **12**, 97-121.

Fischer. *Machinery*, 1939, **53**, 745-53.

Ignat'eva. *Zavod. Lab.*, 1938, **7**, 949-58.

Masi. *Met. ital.*, 1938, **30**, 111-117; *Chimie et Indust.*, **40**, 681.

Mehlig. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 27.

Pastore. *Met. ital.*, 1937, **29**, 163.

Scheibe. *Arch. Eisenhüttenw.*, 1931, **4**, 579-86.

Schliessmann. *Arch. Eisenhüttenw.*, 1934, **8**, 159-64.

Schliessmann and Zanker. *Arch. Eisenhüttenw.*, 1937, **10**, 345-52; 1937, **10**, 383-94.

Twyman and Harvey. *Engineering*, 1932, **134**, 437; *J. Iron Steel Inst.*, 1932.

Vincent, et al. *Metals and Alloys*, 1938, **9**, 27.  
(In cast iron.)

#### IN COBALT STEELS; Cr-Co AND Fe-Co.

Kar. *Chemist Analyst*, 1935, **24**, No. 2, 6.

#### IN TUNGSTEN AND Fe-W.

Smith. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 350.

## Molybdenum

The application by Knowles in 1932 of  $\alpha$ -benzoin-oxime to the determination of molybdenum is of no less importance than Tschugaeff's dimethylglyoxime reaction with nickel or Ilinski's separation of cobalt as the  $\alpha$ -nitroso- $\beta$ -naphthol complex. Knowles devised simple conditions under which  $\alpha$ -benzoin-oxime is virtually specific for molybdenum and the process has come to be widely adopted, especially for those irons and steels that contain vanadium.

Precipitation as lead molybdate was investigated by Taylor-Austin, who found that when applied to cast iron modifications become necessary to counteract the interference of phosphorus. In addition, it was found that the precipitate is affected by variations in the concentration of ammonium salts.

Volumetric procedures include reduction by means of amalgams, and many authors describe potentiometric methods for conjointly estimating molybdenum and accompanying elements.

The marked advantages of the photo-electric absorptiometer in colorimetry have led to the development of conditions under which extraction of the thiocyanate complex is no longer necessary.

Very reliable spectrographic technique has been evolved.

## REVIEW.

Klinger. *Arch. Eisenhüttenw.*, 1940, **14**, 157.

(Critical survey of gravimetric, volumetric and colorimetric methods; 63 refs. precipitation with  $H_2S$  in acid solution preferred, unless Cu absent, when  $PbMoO_4$  recommended.)

## GRAVIMETRIC METHODS.

Weighed as lead molybdate.

Bruggemann. *Chem. Ztg.*, 1933, **87**, 863-6.  
( $MoS_3$ -PbAc methods.)

Clarke. *Chemist-Analyst*, 1940, **29**, 83, 86.  
(Rapid method:  $\alpha$ -benzoin oxime complex and filter treated with  $HClO_4$ ,  $HNO_3$ ,  $NH_4OH$ ,  $NH_4OAc$ , and  $Pb(OAc)_2$ .)

Johnson. *Iron Age*, 1933, **132**, No. 2, 16.  
( $SuCl_2$ -KCNS-chincholine; red precipitate.)

Khlopin. *Zavod. Lab.*, 1934, **3**, 297-301.  
( $MoS_3$ -Pb Ac method and review.)

Knowles. *Bur. Stand. J. Res.*, 1932, **9**, 1.  
(Precipitation by means of  $\alpha$ -benzoin-monooxime.)

Rousseau. *Chimie et Indus*, Special No., 1931, 188-93.  
(V and Fe pptd. by  $Na_2CO_3$ .)

Steele. *Iron Steel Ind.*, 1938, **11**, 267-8.  
(Taylor-Austin method applied to 18:8 steels.)

Sterling and Spuhr. *Ind. Eng. Chem. Anal. ed.*, 1940, **12**, 33.  
*Chem. Age*, 1940, **42**, 155.  
(Benzoin-oxime precipitate dissolved in  $NH_4OH$  and converted to  $PbMoO_4$ .)

Taylor-Austin. *Analyst*, 1937, **62**, 107-117.  
(In cast iron.)

Weirick and McCollum. *Heat Treating and Forging*, 1930, **16**, 1145-6, 1155.  
(Consideration of errors.)

## VOLUMETRIC METHODS.

Andreev. *Zavod. Lab.*, 1937, **6**, 793-7.  
(Reduction with Cd-Hg; titration with  $K_2Cr_2O_7$  using methylene blue.)

Koroda. *Tetsu-to-Hagane*, 1940, **12**, 893.  
(Zn-Hg reduction followed by  $KMnO_4$  titration; in FeMo and ores.)

Panchenko. *J. App. Chem.*, U.S.S.R., 1935, **8**, 361-5.  
(Iodometrically with Ti, U, and V; reduction with amalgams.)

Rousseau. *Chimie et Indus*, Special No., 1931, 188-93.  
(By titration with  $TiCl_3$ .)

Stepin. *Zavod. Lab.*, 1939, **8**, 799.  
(Hg-Reduction in  $3nNHCl$  and titration with  $NH_4VO_3$ .)

## POTENTIOMETRIC.

Brintzinger and Rost. *Z. anal. Chem.*, 1939, **115**, 241-50, 250-7.  
(In complex steels and Fe-Mo.)

Dickens and Brennecke. *Mitt. K.-W. Inst., Eisenfor.*, 1932, **14**, 249-59.

Fogel'son and Kalmuikova. *Zavod. Lab.*, 1936, **5**, 148-51.

Klinger. *Tech. Mitt. Krupp*, 1935, **3**, 41-57.

Rabinovich. *Zavod. Lab.*, 1937, **6**, 504-5.  
(In Fe-Mo by reduction with Zn and titration with  $KMnO_4$ .)

Schaefer. *Arch. Eisenhüttenw.*, 1937, **11**, 297-302.  
(With Cu.)

Sosnovskii. *Zavod. Lab.*, 1934, **3**, 696-8.

Wirtz. *Z. anal. Chem.*, 1939, **116**, 240-3.  
(In FeMo.)

Zan'ko and Shlyakman. *Zavod. Lab.*, 1934, **3**, 777-84.

## COLORIMETRIC METHODS.

Cunningham and Hamner. *Ind. Eng. Chem. Anal. ed.*, 1931, **3**, 106-7.  
( $SuCl_2$ -KCNS.)

Delbart and Dueg. *14me Congr. chim. ind.*, Paris, Oct., 1934.  
(Effect of P on Kessler's  $PbMoO_4$  method.)

Getzov. *Zavod. Lab.*, 1935, **4**, 583.

Geuer. *Chem. App.*, 1938, **25**, 257-8.  
(With V.)

Miloslavskii and Vavilova. *Zavod. Lab.*, 1936, **5**, 12-16.  
(By means of  $2N_2H_4 \cdot H_2SO_4$ .)

Misson. *14me. Congr. chim. ind.*, Paris, Oct., 1934.  
( $SuCl_2$ -KCNS- $Et_2O$ .)

Panchenko. *J. App. Chem.*, U.S.S.R., 1935, **8**, 722-6.  
(By means of sodium ethylxanthate.)

Sperl. *Chem. Ztg.*, 1940, **64**, 363.  
(Small amounts in steel and FeV; ether extraction of  $K_2(MoO)(SCN)_2$ .)

## PHOTOMETRIC.

Davydov and Maltsev. *Zavod. Lab.*, 1939, **8**, 264.

Dietrich and Schmitt. *Metallwirtschaft*, 1938, **17**, 88-9.  
(Solution of 1 g. sample in  $HCl + H_3PO_4$  treated with  $KClO_3$  and NaOH and aliquot used for KCNS- $K_2SnCl_4$  reaction.)

Eder. *Arch. Eisenhüttenw.*, 1937, **11**, 185-7.  
(By the Pulfrich instrument; in steels containing V, Co, Cu, Ta, and Nb.)

Jacowiczowna. *Przemysl. Chem.*, 1939, **23**, 116.  
(A review of methods.)

Keune. *Tech. Mitt. Krupp.*, 1935, **3**, 215-18.  
(By the Pulfrich instrument;  $SuCl_2$ -KCNS method; accuracy  $\pm 0.02\%$  Mo.)

Pfahner and Pacwiczowna. *Przemysl. Chem.*, 1936, **20**, 127-32.

Sokotova. *Aviapromyslenost*, 1939, No. 3, 52.  
(NaCNS and  $SuCl_2$  after separation of Fe and Cr.)

Uzumasa and Doi. *Bull. Chem. Soc., Japan*, 1939, **14**, 337.  
(Concluded that in KCNS- $SuCl_2$  method, possibly  $K_2(MoO)(SCN)_2$  formed.)

## SPECTROGRAPHIC.

Alekseev and Berdichevskaya. *Zavod. Lab.*, 1938, **7**, 603-6.  
(With V.)

Bel'kevich, et al. *Zavod. Lab.*, 1940, **9**, 1279.  
(Spectroscope.)

Matveev. *Zavod. Lab.*, 1937, **6**, 456.  
(For Mo, Cr, Mn, and W, with the spectroscope.)

Sawyer and Vincent. *Proc. Mass. 5th Summer Con.*, 1-7.

Schliesmann and Zanker. *Arch. Eisenhüttenw.*, 1937, **10**, 383-94.  
(With Cr, Si, Mn, Cr.)

## ELECTROLYTIC METHODS.

Lautie. *Bull. Soc. chim.*, 1938, **5**, 1550-2.  
(In 15-25% NaCl using a Ni-cathode.)

## POLAROGRAPHIC.

Stackelberg, et al. *Tech. Mitt. Krupp*, 1939, **2**, 59-85.  
(Curves are given for Mo, Mn, Ni, Co, Cr, V, and W.)

Thanheiser and Williams. *Mitt. K.-W. Met.*, 1939, **21**, 65-78.  
(With Cr and V after removal of Fe by alkali hydroxide.)

## MISCELLANEOUS.

Bertrand. *Bull. Soc. Chim. Belg.*, **41**, 98-103.  
(Qualitative test.)

Getzov. *Zavod. Lab.*, 1935, **4**, 583.  
(Sensitive method using  $SuCl_2$ -paper.)

Johnson. *Iron Age*, 1939, **144**, No. 15, 30-1.  
( $HClO_4$ - $H_2SO_4$ -method; Cr, Ti, Mo, and W do not interfere.)

Montellucci and Gambioli. *Mett. italiana*, 1933, **25**, 12-16.  
(Phenylhydrazine (qualitative) test; Cr does not interfere.)

Shkotova. *Zavod. Lab.*, 1937, **6**, 287-8.  
(Rapid method.)

Yagoda and Fales. *J. Amer. Chem. Soc.*, 1938, **60**, 640.  
(Analytical chemistry of molybdenum.)

## Nickel

In the numerous methods devised, the various chemical and physical means of analysis are well represented. A practical advance in the cyanometric technique is the pre-oxidation of chromium which, in the intensely coloured reduced form, seriously obscures the end-point; little attention has been directed to overcoming the interference of copper and cobalt. Colorimetric methods require further development, since isolation of the element is still necessary. Direct precipitation by dimethylglyoxime from ammoniacal tartrate solution in the joint presence of copper and ferric salts has been found to yield high results; a preliminary reduction of the iron and precipitation from tartrate-acetic-acetate medium combine to inhibit interference.



## PRECIPITATION WITH DIMETHYLGLYOXIME.

- Balz. *Z. anorg. allgem. Chem.*, 1937, **231**, 15-23.  
(Reduction of iron; tartrate-acetate medium.)
- Deichman. *J. App. Chem.*, U.S.S.R., 1935, **8**, 1096.  
(Colorimetric determination in iron ores.)
- Guédras. *Aciers spéciaux*, 1933, **8**, 373.
- Kassler. *Mikrochem.*, 1930, 170.  
(Microchemical.)
- Marunova-Shadrina. *Trudy Vn. Esay. Nauch., Issledov. Inst. Metrol.*, 1937, No. 25, 15.  
(Ether Separation.)
- Mukhina. *Zavod. Lab.*, 1939, **8**, 162.  
(Use of  $\text{HClO}_4$ .)
- Pestelli. *Congr. intern. fonderia*, Milan, 1931, 327-37; *Chimie et Industrie*, **29**, 827.  
(In alloy cast iron; decomposed with alkali peroxide.)
- Pigott. *Indus. Chem.*, 1935, **11**, 273.  
(Ni-Al-Fe alloys.)
- Reichel and Stuzin. *Z. anal. Chem.*, 1938, **113**, 389-419.  
(Preliminary separation as ferricyanide.)
- Scott. *Chemist-Analyst*, 1935, **24**, No. 3, 4.  
(In chrome steels:  $\text{HClO}_4$ -method.)
- Sullivan. *Metals and Alloys*, 1935, **6**, 134.
- Sveshnikov and Smirnova. *Zavod. Lab.*, 1936, **5**, 1250.  
(Removal of iron.)

## CYANOMETRIC TITRATION.

- Charlot. *Bull. Soc. Chim.*, 1936, **5**, 3, 324.  
(In materials containing cobalt.)
- Guédras. *Aciers spéciaux*, 1933, **8**, 373.
- Gel'band. *Zavod. Lab.*, 1934, **3**, 129.  
(Use of sodium pyrophosphate.)
- Golendeev. *Rep. U.S.S.R. Fat and Marg. Inst.*, 1935, No. 2, 22.  
(Using  $\text{H}_3\text{PO}_4$ .)
- Keeble. *Iron Steel Ind.*, 1931, **4**, 389.
- Knoyle. Swansea Tech. Coll. Met. Soc., 1930, Febr. 22.  
(Cu separated by means of  $\text{ZnS}$ .)
- Mukhina and Zolotareva. *Zavod. Lab.*, 1934, **3**, 784.  
(In special steels;  $\text{HClO}_4$  method.)
- Peters. *Metals and Alloys*, 1935, **6**, 278.  
(In chromium steels;  $\text{HClO}_4$  method.)
- Peters. *Chemist-Analyst*, 1937, **26**, 76.  
(In Ni-Cr and Ni-Cr-Fe alloys.)
- Shkotova. *Zavod. Lab.*, 1937, **6**, 1010.  
(Cu removed by decomposing with dilute  $\text{H}_2\text{SO}_4$ .)
- Volkova and Shmulevich. *Zavod. Lab.*, 1936, **5**, 668.  
(Preliminary separation of copper.)
- Vorob'ev. *Zavod. Lab.*, 1935, **4**, 1105.  
(Using  $\text{Na}_2\text{F}_2\text{O}_7$ .)

## POTENTIOMETRIC.

- Bohnoltzer. *Z. anal. Chem.*, 1932, **87**, 401-15.
- Hiltner. *Z. anal. Chem.*, 1933, **95**, 37.  
(Cyanometric method; silver electrodes.)
- Hiltner and Grundmann. *Arch. Eisenhüttenw.*, 1934, **7**, 461.  
(Cyanometric method.)
- Khlopin. *Zavod. Lab.*, 1933, **2**, No. 7, 28.

## PHOTOMETRIC.

- Boyer. *Ind. Eng. Chem. Anal. ed.*, 1938, **10**, 175.  
( $\text{AgNO}_3$ -KCN titration.)
- Dietrich and Schmitt. *Z. anal. Chem.*, 1937, 109, 25-31.  
( $\text{NaBrO}$ -dimethylglyoxime complex.)
- Korenman and Voronov. *Zavod. Lab.*, 1939, **8**, 664.  
(Bromination of dimethylglyoxime complex.)
- Maltsev and Temirenko. *Zavod. Lab.*, 1940, **9**, 386.  
(Bromination of dimethylglyoxime complex.)
- Murray and Ashley. *Ind. Eng. Chem. Anal. ed.* (1938), **10**, 1-5.  
(Pulfrich instrument,  $\text{Br}_2$ -aq. + dimethylglyoxime.)

## MISCELLANEOUS.

- Peshkova. *Zavod. Lab.*, 1940, **9**, 407.  
(a-benzylidioxime is preferable.)

## ELECTROLYTIC.

- Boberkova and Novitskaya. *Zavod. Lab.*, 1937, **6**, 882.
- Glazunov and Krivohlav. *Z. Physik Chem.*, 1932, **161**, 373-88.
- Khlopin. *Zavod. Lab.*, 1935, **4**, 289; 1937, **6**, 882.
- Lyalikov and Usatenko. *Zavod. Lab.*, 1938, **7**, 1100-5.  
(Polarographic.)
- Maassen. *Angew. Chem.*, 1937, **50**, 375.  
(Polarographic.)
- Thaneiser and Maassen. *Arch. Eisenhüttenw.*, 1937, **10**, 441-62; *Mitt. K.-W. Inst., Eisenf.r.*, 1937, **19**, 26-47.  
(Polarographic.)

## SPECTROGRAPHIC.

- Bardocz. *Magyar Mernok-Epítészegeti Közlem.*, 1938, **12**, 97-121.
- Limner. *Z. wiss. Phot.*, 1938, **37**, 41-50.
- Sawyer and Vincen. *Proc. 5th Summer Conf., Mass. Inst. Tech.*, 1938.
- Shimur and Takasu. *J. Iron Steel Inst., Japan*, 1939, **16**, 961.  
(Analysis of Fe-Ni-Mn alloys by means of X-rays.)
- Tryman and Harvey. *Engineering*, 1932, 134, 487. *J. Iron Steel Inst.*, 1932.

(To be continued.)

# Anodic Coatings on Aluminium

Some tests have been carried out to measure the brittleness of various types of anodic coatings on aluminium alloy sheet, and to determine whether such coatings were brittle enough to be used in the "brittle coating" method for indicating strain distributions on the surface of a stressed piece. The results have given data of general interest.

THE widely employed anodic treatment of aluminium and its alloys to increase corrosion and wear resistance may be accomplished by either chemical or electrolytic processes. Such artificial oxide coatings may be of various degrees of hardness, depending on the manufacturing method used, and show corresponding variations in brittleness. The coatings formed by chemical treatment only are relatively soft, and may even be of a powdery nature at times, but the oxide coatings produced by electrochemical means are quite hard, and adhere tenaciously to the base metal, and compare in hardness with their mineral counterpart, corundum. The thick oxide coatings produced in sulphuric or oxalic acid electrolyte by anodic treatment or below room temperature are hard, abrasion-resistant and corrosion-resistant, while the films produced in chromic acid under the usual operating conditions are much thinner. These hard oxide films on aluminium are naturally also brittle. Recently, some tests

have been carried out by H. N. Hill and R. B. Mason\* to measure the brittleness of various types of anodic coatings on aluminium alloy sheet. These tests were made to determine whether or not such coatings were brittle enough to be used in the "brittle coating" method for indicating strain distributions on the surface of a stressed piece, and at the same time have supplied data of general interest in connection with the commercial application of such coatings.

A qualitative observation of brittleness is the fact that a crackling noise can generally be heard when the underlying metal is bent slightly. Fine hairline cracks can be seen with the naked eye, provided the incident light strikes the surface at the proper angle, and these extremely fine cracks may almost entirely disappear when the metal is bent back to its original position. When aluminium sheet, coated with a hard oxide film, is cut or scratched, fine hairline cracks

\* *Metals and Alloys*, 1942, vol. 16, No. 6, pp. 972-975.

will develop in the region where the base metal was disturbed. Although the oxide coating is brittle, it adheres tenaciously to the base metal and repeated bending does not cause it to scale off. Anodic coatings, besides being hard and brittle, are also porous, with the pores running from the oxide surface to the metal base and give the coating a fibrous structure. An oxide coating can be sealed, and this is usually accomplished by immersion in boiling water.

For the purpose of evaluating the brittleness of various anodic coatings, six standard tensile test specimens were machined from aluminium alloy sheet having a normal composition of 1.5% magnesium, 0.7% silicon, and 0.25% chromium. This alloy had an elastic limit of about 22,000 lb. per sq. in., and since the modulus of elasticity was about 10,000,000 lb. per sq. in., the unit strain was about 0.0022 in. per inch. Therefore, for the coating to crack within the elastic range of the base metal, cracks had to occur at some value of unit strain less than 0.0022 in. per inch.

The test specimens were given various anodic treatments (Table I), and were then loaded in an Amsler hydraulic testing machine. Load was applied in increments, so as to produce uniform increments of strain, and strain was measured with an extensometer and after each increment of strain had been attained, one side of the specimen was examined microscopically.

TABLE I.  
ANODIC TREATMENTS GIVEN TO TEST SPECIMENS.

Test No.	Electrolyte.	Current Density Amp. per Sq. Ft.	Temperature, ° F.	E.M.F., Volts.	Time, Mins.	Sealing Treatment.
1	H <sub>2</sub> SO <sub>4</sub> , 15%	12	76	17	30	Unsealed.
2	H <sub>2</sub> SO <sub>4</sub> , 15%	12	76	17	30	30 mins. in boiling distilled water
3.	W <sub>2</sub> SO <sub>4</sub> , 15%	12	76	17	30	30 mins. in boiling 5% K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>
4	H <sub>2</sub> SO <sub>4</sub> , 7%	12	74-83	20	30	Unsealed.
5	(COOH) <sub>2</sub> , 3%	12	80-97	46	30	Unsealed.
6	CrO <sub>3</sub> , 9.5%	2.5	95	40	30	Unsealed.

Because of the slight stress concentration produced by the change in section; cracks in the coating appeared first at the point of tangency of the filler and the straight side of the reduced portion of the test specimen. One such region was examined continuously as each increment of strain was being applied, and the strain reading was recorded at which the first crack was observed.

The appearance of a crack at the point of tangency was followed by the formation of cracks on the reduced portion of the specimen, at a slight increase in the amount of strain, and further straining increased the number of cracks. One of the first cracks to appear on the reduced portion was marked as a reference, and as each additional increment of strain was attained, the distance was measured between this reference crack and the fifth crack from it, and this reading gave a measure of the spacing of the cracks. The data obtained from the various specimens was plotted in a series of curves showing the density of cracks, expressed as the number of cracks per inch plotted against the unit strain.

Tests were also carried out to determine whether cracks which are too small to be readily seen under the microscope might be found when an anodically coated aluminium specimen was bent or stressed. When an oxide-coated specimen of aluminium is placed in a solution of sodium chloride and copper nitrate, the ions of the solution penetrate the weak spots, and copper is deposited on the aluminium and is readily visible. A piece of aluminium sheet was anodically coated in 15% sulphuric acid for 30 mins. and sealed in boiling water. The coated specimen was then supported at both ends and stressed to a point slightly less than that required to produce visible cracking of the coating, after which it was immersed in the test solution for 30 mins. No indication of any cracks in the oxide coating were found.

Another specimen was bent until definite cracks appeared in the oxide coating. The limiting cracks which could be seen under the microscope were marked and the specimen placed in the sodium chloride-copper nitrate solution for 5 mins. Copper was deposited along the cracks, but there was no indication of other cracks in the oxide coating beyond the region of visible cracks. From the results of these tests, it was concluded that either the method of testing was not sensitive enough to detect invisible cracks or, as is probably the case, no cracks occur in the oxide coating which are not visible under the microscope. In Table II are given the values of unit strain corresponding to the appearance of the first cracks in the various specimens.

TABLE II.  
UNIT STRAINS AT WHICH FIRST CRACKS APPEARED IN THE STRAIGHT PORTION OF THE SPECIMEN.

Specimen No.	Unit Strain at First Crack in per Inch.	Specimen No.	Unit Strain at First Crack in per Inch.
1	0.0029	4	0.0036
2	0.0040	5	0.0045
3	0.0039	6	0.0155

The results obtained from the various tests appeared to indicate that oxide coatings produced on aluminium alloy sheet by anodic treatment were not brittle enough to be satisfactorily used to indicate strain distribution on the surface of a stressed specimen. Cracks did not occur in the coating until the material had been strained beyond its elastic limit. Sealing by immersion in boiling distilled water or a hot dichromate solution slightly reduced the brittleness of the coating. The data obtained also showed that coatings were surprisingly elastic, in spite of their mineral-like hardness.

## Twenty-Five Years of Service

CONGRATULATIONS are due to Wild-Barfield Electric Furnaces, Ltd., on recently passing their twenty-fifth anniversary. Under normal circumstances it is probable that the Company would have marked the occasion by appropriate celebrations, but the occasion is worthy of note.

The formation of this Company in the last Great War was based very largely on technical collaboration between Mr. L. W. Wild and the late Mr. E. P. Barfield in connection with the national war effort held at that time. In the intervening years there has been enormous progress in heat-treatment processes. It is now recognised that too much emphasis cannot be placed on the importance of metallurgical control of all heat-treatment operations in order to develop in the materials treated the properties desired. Specifications have become so exacting that close control of every process is essential to success in meeting these requirements consistently. It is now necessary not only to control the temperature and the rate at which heat is absorbed by the material undergoing heat-treatment, but also the conditions under which the material is heated and the rate at which it is cooled.

Improved heat-treatment technique has been made possible by greatly improved furnace equipment; furnace plant has been made accurate and capable of producing conditions which assist so much in meeting the requirements for more exacting properties from materials treated, and Wild-Barfield Electric Furnaces, Ltd., have contributed, and are contributing to-day to this progress. The technical achievements of this Company have been referred to from time to time in this journal, but present conditions prevent the publication of detailed information on more recent achievements; it is noteworthy, however, that the whole of the organisation, now operating on a much larger scale than hitherto, has only one object in view—to supply the maximum output of reliable heat-treatment equipment to industry in the minimum of time in the present emergency.

